EXPLOITING REMOTELY PILOTED AIRCRAFT: UNDERSTANDING THE IMPACT OF STRATEGY ON THE APPROACH TO AUTONOMY

BY

ERIC B. NELSON, LIEUTENANT COLONEL, USAF

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APPROVAL

The undersigned certify that this thesis meets master's-level standards of research, argumentation, and expression.

STERLING M. PAVELEC, Ph.D. (Date)

TIMOTHY P. SCHULTZ, Col., USAF, (Date)

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The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Air Force, or Air University.

ABOUT THE AUTHOR

Lieutenant Colonel Eric B. Nelson began his career in 1996 as an officer in the United States Air Force, after earning a Bachelor of Science degree in Mechanical Engineering from the United States Air Force Academy (USAFA) and receiving his commission. As an initial assignment, he demonstrated the first successful active control of a full-sized turbo shaft engine that increased the maximum engine thrust by four percent, while earning his Master of Science in Aeronautical and Astronautical Engineering at Massachusetts Institute of Technology (MIT) in 1998. After reassignment to the Air Force Research Laboratory, Lieutenant Colonel Nelson's work as an Aerospace Engineer in control theory research led to the first ever Air Force neural network flight test of the X-36 unmanned air vehicle (UAV). In 2000, Lieutenant Colonel Nelson became a Technologies Analyst at the National Air and Space Intelligence Center (NASIC). He led a team that explored UAV performance capabilities for intelligence review. Meanwhile, Lieutenant Colonel Nelson completed his Masters in Business Administration at Wright State University in 2001. A year later, Lieutenant Colonel Nelson attended the Air Force Institute of Technology (AFIT) where he derived new explicit regression algorithms for parameter estimation to solve problems that address linearization effects or unforeseen trim changes. He completed the Space Systems Engineering PhD in Electrical Engineering in 2005. For the next three years, Lieutenant Colonel Nelson worked at the National Reconnaissance Office as Program Manager, Spacecraft Power and Attitude Control and oversaw construction of 11 NRO Signals Intelligence (SIGINT) satellites. He served as the Principal Deputy Director's Executive Officer during his final year at the NRO. In 2009, Lieutenant Colonel Nelson proposed an organizational construct for Acquiring Remotely Piloted Aircraft (RPA) during his Masters degree in Military Arts from Air Command and Staff College (ACSC). While attending the School of Advanced Air and Space Studies (SAASS) Lieutenant Colonel Nelson is exploring the strategic impact of RPA developments that increase platform autonomy while completing the Masters of Philosophy degree in Military Strategy.

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ABSTRACT

This thesis explores the strategic impact of human systems integration (HSI) developments on Remotely Piloted Aircraft (RPA) technology to increase autonomy. A focus on HSI reveals strategic considerations to rethink the use of the Air Force's preferred organizational construct for the acquisitions. Considering the working relationship of the RPA community as it exists today, and identifying the potential drivers of increasing autonomy, provide for an alternate acquisitions model. Specifically, anticipated strategy motivates a technological development sequences towards two thrusts of effort. The first pertains to technologies that enhance platform-centric RPA autonomy. These innovations facilitate the ability of an individual machine to self-monitor critical functions and to devise its own missions. The second thrust encompasses the technologies that will enable a platform to contribute to RPA network objectives. By coupling the benefits of these two technological components, strategic opportunities emerge that sustain asymmetric advantage against rivals. Today's acquisitions approach contributes to heavy manpower requirements for platform operation, operator awareness limitations, and difficulties that hinder increasingly complex multi-vehicle missions. Although increased autonomy promises to alleviate some human burdens in near future innovation, the Air Force's acquisitions organizational construct threatens to constrain autonomous technology innovation if unaddressed. This thesis highlights the need for a predictable communication format and mechanism to link customer objectives with autonomous RPA research and development. The USAF must rethink working relationships to acquire a sustainable RPA network. An understanding of strategic purpose helps to inform acquisition development, thereby serving as a guide to prioritize interim objectives (ends) and approach (ways) that ultimately equips the warfighter (with the appropriate means). Finally, this thesis equips the strategist with a systematic framework from which to reassess the RPA acquisition scenario to accommodate for evolving context that motivates reprioritization towards innovation.

CONTENTS

INTRODUCTION

RPA Autonomy: What Does the Concept Mean?

Autonomous Remotely Piloted Aircraft (RPAs) describe unmanned platforms that can control or direct themselves. To achieve autonomy, some argue that a platform needs to sense, perceive, analyze, communicate, plan, decide, and execute an assigned objective on its own.[1] The platform performs these functions for itself and successfully contributes to the mission objectives of the larger group to which it is assigned.[2] Others contend that rather than trying to realize some ideal concept of autonomy, one should judge progress against other platforms with known capabilities and manpower needs. This thesis adopts the latter view. Hence, the first chapter, a description of current RPA technology, serves as a reference point from which to extrapolate future RPA developments that improve autonomy.

Critical technologies that foster RPA autonomy occur in one of two broad categories. The first pertains to advancements that relate to a platform as an independent entity. Innovations of this type help an individual machine to take care of a greater share of its own functions and perform its own missions. The second includes those advancements that enable a platform to interact as part of a group. Both categories merit attention since platform-centric and group-centric autonomy advances appeal to different subsets of the Air Force user community. As a result of this conceptual division between technological advancements, warfighters can better plan for how they might exploit the anticipated developments as they mature.

Excitement about Future RPAs

The US Air Force (USAF) is in transition. The Secretary of the Air Force's (SecAF) Unmanned Aircraft Systems (UAS) flight plan calls for his service to promote remotely piloted aircraft technology. This advocacy includes a strong push for concepts such as highly automated and coordinated RPA missions, cooperative target

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[1] Hui-Min Huang, Elena Messina, and James Albus, "Autonomy Levels for Unmanned Systems (ALFUS) Framework," *NIST Special Publication 1011-II-1.0*, December 2007, 16.
[2] Hui-Min Huang, Elena Messina, and James Albus, "Autonomy Levels for Unmanned Systems (ALFUS) Framework," 16.

engagements, and even formation flight.[3] Other policy documents echo these sentiments, such as the SecAF's *Technology Horizons* vision for USAF Science and Technology and comprehensive studies by the Air Force Scientific Advisory Board.[4] Although the SecAF plan dedicates much critical thought to the desired capabilities and organizational restructuring of USAF rated personnel, the document fails to link future strategy to the technological developments that increase autonomy.

Although these visionary documents emphasize the mechanization of cognitive processes to control weapon development, careful assessment must shape expectations for the air domain to mitigate disruption of a well-established organizational construct. The very conversation about RPA autonomy itself needs guidance in order to coordinate technological developments. Such dialogue would tame runaway technological sensationalism that tends to undermine individual buy-in and commitment to change. For instance, technology futurist Ray Kurzweil extrapolated certain examples of rapid advancement that occur at an accelerating rate.[5] He then attempted to generalize these findings to claim that one should think of technology as a "human-sponsored" variation of evolution that expands at an exponential rate.[6] Other enthusiasts, such as P.W. Singer, have extrapolated Kurzweil's line of thinking to propose an aerial domain ruled by ubiquitous, autonomous RPAs.[7] By failing to differentiate between applications of remote, stand-off weaponry and autonomous flying machines, Singer makes some dramatic leaps that link a vision of robotic self-awareness to a new type of lethal war

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[3] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, (Washington DC: Headquarters, United States Air Force, 18 May 2009), 49. The SecAF endorses numerous capability developments, as part of a long-term visionary flight plan for the 2025-2047 timeframe.

[4] Secretary of the Air Force Michael B. Donley, *Technology Horizons: A Vision for Air Force Science and Technology*, (Washington DC: Headquarters Air Force, 15 May 2010), i, ii. Also see Greg Zacharias and Mark Maybury, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, (Washington DC: Scientific Advisory Board, 7 July 2010), 7.

[5] Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*, (New York: Penguin Books, 2005), 47-72.

[6] Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*, 42.

[7] P.W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, (New York: Penguin Books, 2009), 97-98, 126, 128. Relying on Ray Kurzweil's observations and hypothesis, Singer revealed that humans had difficulty controlling multiple RPAs simultaneously while using traditional piloting approaches. He then asserted that the speed, confusion, and information overload of modern-day war will soon move the whole process outside of "human space."

experience.[8] His assertions lead an uninformed reader to believe that even today's RPAs have the ability to use their own agency to kill and destroy. In order to construct a visionary framework that sets strategic direction for increasingly autonomous RPA technology while constraining such hype, it is important to connect anticipated technological developments to national strategic objectives.

By attempting to understand what might guide technology development, one may discover how social influences shape RPA autonomous concepts. A common language about technological contributors to RPA autonomy facilitates additional innovative advances.[9] It fosters the ability to communicate advancements, articulate a request for help, and provide ideas for additional innovation to further advance autonomy. The USAF acquisitions community seeks to introduce means that promote warfighter effectiveness. Does this motivation extend uniformly through the organizations that contribute to the innovation? The Air Force should investigate what motivates the innovation in sub organizations, such as the Air Force Research Laboratory (AFRL).

During a period of change, some within an organization may fear the emergence of new technology as an unwanted source of uncertainty pitted against their personal vested interests. Bob Seidensticker introduced the concept of the *technology spotlight* as a method to explain the nature of technological change as it confronts such social challenges.[10] The *technology spotlight* recognizes that certain individual technologies can grow exponentially at times, but makes allowances for government policy, market economics, tough technical problems, and organizational resistance.[11] In the case of

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[8] P.W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, 116. Systems like the MQ-9 Reaper work as a remote weapon system under human control. Singer introduces a barrage of concepts, such as automatic man-made object detection, coherent change detection, sensors that can recognize and categorize humans, and after making sense of the events, can bomb high-priority human targets, seemingly on their own.

[9] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed., (Chicago: University of Chicago Press, 1996), 17-18. Kuhn describes the emergence of a paradigm, which generates a convention of inquiry. He recognizes Bacon's observation that truth emerges more readily from error while mimicking a convention of exploration than from the confusion associated without a working paradigm.

[10] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, (San Francisco: Berrett-Koehler Publishers, 2006), 117. Seidensticker uses the technology spotlight to highlight important attributes or contributors to an emerging technology. By creating an awareness based on a common understanding, advocates can influence the development process and the manner in which the artifact is eventually used. A specific realization is not predestined; rather, the use of an artifact is socially constructed to acceptable application.

[11] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, 119.

RPAs, AFRL seeks to spotlight the emerging technology of RPA autonomy by communicating its capabilities more clearly to the greater acquisition community and the Air Force at large. Such transparency will encourage dialogue about how to optimize the use of emerging technology.

The laboratory seeks to mature technology concepts that satisfy anticipated warfighter requirements. Manuel De Landa developed a process that describes the efforts of men to create order out of chaos within an uncertain context, which he defines as the *machinic phylum*.[12] With the very development of RPAs, a sense of chaos could emerge in the minds of those that exploit the air domain. The very essence of the traditional weapon of choice, the manned aircraft, is seemingly threatened.[13] Yet, a commander needs to discover and apply tactics, operations, and strategies that help him or her employ these new RPA weapons as a part of a coherent effort.[14] So, the leader's task is to define the *machinic phylum* that uses these new means to pursue strategic objectives. In the case studied here, the Air Force Research Laboratory supports the future commander's ability to exploit RPA technology to deliver complementary effects from and within a dynamic aerial battlespace.

Research Question

What hinders the Air Force from capitalizing on Remotely Piloted Aircraft improvements that increase autonomy? The USAF has cultivated arguably one of the most prolific acquisition communities.[15] The foundation for much of its success lies in its basic organizational structure, the systems program office (SPO). For decades, the USAF has used the organizational construct to deliver modern aircraft and space and

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[12] Manuel De Landa, *War in the Age of Intelligent Machines*, 4th printing, (New York: Zone Books, 1998), 20. De Landa defines machinic phylum as a set of self-organizing processes within a chaotic, uncertain universe. These include all processes in which a group of previously disconnected elements suddenly reach a critical point such that they begin to cooperate as a higher level entity. This concept can extend to the nature of airmen, as he or she has created order in their approach to warfighting.
[13] Carl H. Builder. *The Icarus Syndrome*, (New Brunswick, NJ: Transaction Publishers, 2003), 35.
[14] Manuel De Landa, *War in the Age of Intelligent Machines*, 23. For ease of understanding, De Landa's concepts are simplified to match a 2011 conception of the levels of war. De Landa described tactics as the art of assembling men and weapons to win a particular battle. Strategy is the art of assembling battles into a coherent war that achieves the given political objective.
[15] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, (New York: Vintage, 2000) 69.

missile systems.[16] The SPO structure focuses on platform-centric production, which should facilitate autonomy enhancements for single RPA operations. However, to develop autonomy initiatives that help multiple RPAs of diverse platform-type to work together as part of sophisticated joint network, the USAF should look for alternative organization arrangements.

Vehicles working within such a multi-platform arrangement rely upon agreed standard interfaces to function as a group. The SPO concentrates on improving systems individually instead of balancing potential improvement to interoperability across multiple programs. In addition to cross-production challenges, the informal working relationships relied upon today do not support the coordination between SPOs and the laboratories needed to improve interoperability. For example, SPOs within Aeronautical Systems Center (ASC) cannot assign work to entities within AFRL. The production entities can appeal for help, but such requests do not bind the laboratories to achieving a certain result. No meaningful compliance mechanism rewards success or punishes failure.

The AFRL is the forerunner for many of these RPA automation technologies and finds itself in the process of maturing many of the concepts. Specifically, the Secretary of the Air Force asked the Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/RH) to develop technologies which promote autonomy.[17] Furthermore, he wants the laboratory to prepare the USAF to anticipate the effects from increased autonomy.[18] Yet, authoritative guidance such as the *UAS Flight Plan* fails to

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[16] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, 69-70.

[17] Greg Zacharias and Mark Maybury, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, 8, 13. Also see Secretary of the Air Force Michael B. Donley, *Technology Horizons: A Vision for Air Force Science and Technology*, 96, 112-14. The Air Force Research Laboratory Commander must align its science and technology portfolio with that specified in the Technology Horizons vision. Autonomous systems lead the list of key technology areas. AFRL is also charged with the task of identifying the underlying technology developments and work to resolve challenges that might thwart its realization.

[18] Secretary of the Air Force Michael B. Donley, *Technology Horizons: A Vision for Air Force Science and Technology*, 115. The Air Force Research Laboratory commander is asked to support the SecAF's Acquisition Air Staff to improve aspects of the science and technology management process. Also see Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 31,54. The UAS Flight plan more specifically calls on the Aeronautical Systems Center focus on the institutional integration required to realize the UAS for the Air Force. AFRL/RH is specifically charged with helping all UAS teams requiring Human System Integration (HSI) expertise, to include the technical subject matter experts (SMEs) and support to the SPOs.

identify any specific measure of performance. The acquisitions community should start a dialogue about how changes in the organizational template could resolve shortcomings that prohibit the new cooperative-controlled, multi-RPA capabilities.

Problem Background and Significance

The USAF increasingly values RPAs as a weapons choice. In spite of anticipated Department of Defense (DoD) spending cuts of as much as $300 billion in 2011, the Secretary of Defense (SecDEF) proposed an increase in expenditures to procure MQ-9 Reapers and train more RPA operators.[19] Specifically, the SecDEF approved the USAF initiative to enlarge the operational wings that fly RPAs.[20] This growth requires a complementary increase in support personnel allocations, such as maintenance, logistics, and research and development (R&D). As the value derived from RPAs grows, the desire for additional oversight expands. This interest accentuates the need for effective communication throughout the acquisition organizations charged with developing the weapon systems. The acquisition community also needs technology advancement projections to explain progress, thereby helping to justify increased budgetary resources.

The research arm of the acquisition community often pursues diverse capabilities as the desired end state, rather than as a means to achieve an end. The visionary *UAS Flight Plan* captures this capability-driven motivation while devoting an entire annex to autonomous capabilities.[21] Initial efforts to foster communication about technology developments emphasize the RPA autonomous possibilities too much, as they relate to current or anticipated programs.[22] The emphasis placed upon programs seems focused on current programs justification, rather than on strategies that would employ RPA autonomous developments.

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[19] Robert M. Gates, "Statement on Department Budget and Efficiencies," US Department of Defense Speech, http://www.defense.gov, 6 January 2011, 3, 5.
[20] Robert M. Gates, "Statement on Department Budget and Efficiencies," 5.
[21] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 33-51. This document includes many examples of autonomous capabilities, such as modularity, swarms, manned-unmanned wingmen, and platform-centric autonomous capabilities, to name a few.
[22] Christopher A. Miller, "Supervisory Control Frameworks: Operationalizing the Radical Simplification," *Smart Information Flow Technologies Conference*, 17 December 2010, 10.

A second, more sophisticated analysis uses a metrics-based approach but still seeks to account for a capability tradeoff against an absolute definition of autonomy.[23] The approach uses ten metrics to assess the state of autonomy along the lines of seven root capabilities.[24] Even though this approach captures numerous aspects of complexity about autonomous behavior, the approach lacks a linkage to anticipated external threats. Because the approach lacks a strategic connection, the audience loses sight of the purpose. This approach would fail as a mechanism to try to facilitate communication between entities of the RPA community. Despite the current state of communication challenges, AFRL/RH successfully articulates an agenda about realizing RPA autonomy.

AFRL's Human Effectiveness directorate identifies four critical mission management technologies that enable the transition from today's stand alone, human intensive RPAs to those anticipated for the future. The critical mission capabilities include those that address 1) operator situational awareness, 2) prioritization of functions to automate, 3) context-determined amount of automation, and 4) manned-unmanned platform interaction.[25] Four mission management categories subsume many underlying technologies that enable the operator to do more tasks. Authoritative oversight recommends that the AFRL seek ways to reduce the number of personnel needed to handle an RPA.[26] The R&D community can help their customers' anticipated manpower requirement by advancing autonomy-based technologies that foster task efficiency in a chaotic operational environment. Anticipating the need for multiple platform operations represents the crux of this thesis. In order to emphasize the importance of this concept, each of the four chapters develops a theme, explained below, through case study analysis.

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[23] Hui-Min Huang, Elena Messina, and James Albus, "Autonomy Levels for Unmanned Systems (ALFUS) Framework", 46.

[24] Hui-Min Huang, Elena Messina, and James Albus, "Autonomy Levels for Unmanned Systems (ALFUS) Framework", 17, 47-48. Huang defines the seven root autonomous capabilities as: sensing, perceiving, analyzing, planning, deciding, acting, and communicating. She asks the community to assess the maturity of each capability against a number of prescribed metrics. To depict the rigor, the authors prescribe the following metrics for the perceiving root autonomous capability. 1) robotic initiation, 2) the ratio of human planning time to mission time, 3) the ratio of human intervention time to mission time, 4) the commanding level at which intervention occurs, 5) workload skill, 6) robotic independence. The formula compiles a weighted summation of all of the metrics. The output prescribes a level of RPA autonomy from the ideal.

[25] Mark Draper, "Supervisory Control Interface Research for Next Generation UAS," *Human Effectiveness Directorate, Air Force Research Laboratory*, 11 May 2010, 4.

[26] Greg Zacharias and Mark Maybury, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, 6, 16.

Theme 1: Acquisition of RPA Autonomy

Perhaps the best way to articulate a vision for RPA development is to illustrate the autonomous evolution. Figure 1 (p. 87) graphically represents three likely trends depicted by curves that change with time. While not prescriptive, it displays the general concepts of how the Air Force can envision RPA advancement. The timeframe on the horizontal axis represents the independent variable. The dependent variables on the vertical axis anticipate three trends. The first variable suggests that autonomy will increase with time. An evaluation of return on autonomy-based R&D reflects a cost-benefit determination that will eventually restrict continued development in this area.[27] Like other technological developments, R&D efforts will flow to other pursuits upon reaching a point of diminishing returns.[28] The second dependent variable depicts the number of RPA platforms in the aerial battlespace. The figure depicts this variable as lagging the autonomy variable as time progresses. Although many factors will likely contribute to the lag, the inability to realize group-RPA applications will predominate. The third dependent variable depicts an eventual reduction in the number of people required to operate the growing network RPAs within the aerial battlespace. Certain norms established with respect to RPA operation reinforce the need for involving many people.[29] Although technological limitations sustain the norm for high manpower requirements over time, the strategic environment eventually forces a dramatic recharacterization. The unique contributions that humans make to the dynamic aerial battlespace limit the rate of manpower reduction as the number reaches a lower limit.[30]

As a thematic device, Figure 1 serves as a visual representation of the four case studies that frame the corresponding chapters of this thesis. In other words, the independent variable of time divides the chapters. This segmentation of context with time bounds the content from which to analyze the three aforementioned dependent variables, namely autonomy, the number of unmanned platforms interacting within a heterogeneous battlespace, and the manpower required to operate RPAs in the war zone.

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[27] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, 30.
[28] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, 31, 34.
[29] Robert Jervis, *Perception and Misperception in International Politics*, (Princeton, NJ: Princeton University Press, 1976), 117.
[30] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, 213-18. Seidensticker presents a number of fallacies pertaining to the extent of technological hype. These considerations collectively reinforce the perspective that some artificially developed will not exceed those projected by a human.

As advances in multi-RPA automation improve, a second theme differentiates two competing objectives that will continue to fragment the focus of R&D advancements.

Theme 1 plays a special role to formulate warfighter strategy about RPAs, thereby informing and driving acquisition strategy as well. This thesis relies on a framework proposed by John Warden to envision strategy for RPA autonomous development.[31] Warden advocates a process of characterizing a conceivable environment to create a *Future Picture*, or a compelling description of what the future reality becomes.[32] This construct helps the strategist to think about new ways of doing business.[33] Because Chapter 1 charts US RPA acquisitions to the present, the past informs the means, ways, and ends consistent with a *Picture* of RPA autonomous development as they exist today. Chapters 2 through 4 represent future timeframes, so the thesis relies on hypothetical future scenarios to become the *Future Picture* as a basis from which to articulate strategy for RPA autonomy.[34] Each chapter demonstrates how this process helps a strategist envision the application of the means. In addition to using the scenarios to craft strategy, the *Future Picture* becomes a tool from which to make essential points about the acquisition organization and innovation.

Theme 2: Multi-Design Points for RPA Acquisitions

The purpose of the multi-design point theme is to analyze two capabilities. The first capability represented by the downward arrows in Figure 2 (p. 88) permits quick, adaptive responses which thwart the enemy's counter measures. Typically, this involves an RPA's ability to react to emerging threats. AFRL/RH ties the ability to dynamically re-plan for environmental uncertainties and to support dynamic shifts in autonomy as enabling technologies to support higher-level critical mission management functions.[35]

The second capability pertains to the ability to execute strategic missions. Notable examples of capabilities that align with this design point include stealth missions

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[31] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 7.
[32] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63.
[33] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 64.
[34] Robert Gilpin's *War & Change in World Politics* serves as the basis from which to think about war and change as a guide to future autonomous technology development for RPAs.
[35] Mark Draper, "Supervisory Control Interface Research for Next Generation UAS," 4.

and platforms that carry imagery sensors for change detection.[36] Planners typically have time to derive platform utilization routes in advance to maximize mission effectiveness. The context of such an approach may entail a mission planner's ability to orchestrate technologies that foster a direct (overwhelm with force) or indirect (sneak in with an unexpected blow) method of attack, depending upon the circumstance. The underlying technologies that are driving autonomy related to this second capability differ significantly from those motivating the former.

Although one could build an RPA system that represents some compromise between two design points, the implications of such a decision are greater for RPAs than manned aircraft.[37] The acquisition community should reference the role that the human pilot can serve in innovating and improvising. The 1920s aircraft designers made a number of conscious decisions that led them to abandon Douhet's *battleplane* concept.[38] Experience prompted aerial warfighters to seek specific platforms to perform specific missions, hence the development of such aircraft as fast, agile fighters and high-flying reconnaissance platforms. Similarly, warfighters recognized the need to maximize mission effectiveness along functional lines, as filled by bombers, transport, air refuelers, and surveillance.[39] Although one can make a reasonable argument that multi-role platforms provide a balance of capabilities towards competing objectives, the design solution imposes a compromise that diminishes the ability to perform either mission to some extent. The human pilot, however, can adapt the ways in which he or she use the aircraft to offset performance loss. Because the human does not perceive the situation from the platform in RPAs, some of the ability to improvise is lost. Arguably, the need to maintain this convention for multi-point design still exists for RPAs. Yet, many

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[36] Mark Draper, Human Effectiveness Directorate, Air Force Research Laboratory (AFRL/RH), Interview, 18 February 2011.

[37] Designers balance performance attributes to ensure that the resulting platform can satisfy requirements at each operational design point independently.

[38] Giulio Douhet, *The Command of the Air*, tran by Dino Ferrari, (Tuscaloosa, AL: University of Alabama, 1921/1998), 117-19. Ferrari indicates that in many respects, the plane Douhet described resembles a modern Flying Fortress. Douhet envisioned a number of additional attributes that exceed the performance of a B-17. But the most distinguishing characteristic is that an entire Air Force should be comprised of this battleplane. From the baseline, each manned platform could be tailored to accentuate certain perform objectives, thereby enabling some flexibility towards unique missions. Douhet reductionist design logic occurs for a number of reasons, but the most prominent contributor pertains to his assumption of invulnerability when flying with adequate numbers.

[39] C3I is an acronym that represents Command, Control, Communications, and Information.

examples for anticipated RPA design superimpose competing design point objectives for flexibility and effectiveness.[40] RPA designers should avoid reductionist design assumptions, and continue to design to principles proven by aircraft design unless a reason emerges to reconsider the approach.

Four Dimensions to Characterize Each Case Study

Each of the chapters will explore four dimensions used to characterize autonomy for RPAs: strategic focus, organizations, technology drivers, and their overall interfaces. This holistic approach recognizes that RPA acquisitions involve much more than just the artifact itself.[41] Indeed, one cannot interpret the evolution of large technological systems without considering these broad dimensions. The following paragraphs explain each dimension in greater detail.

The first dimension emphasizes the importance of strategic focus to each case study. Because asymmetric technological advantage can contribute significantly to victory, militaries seek to innovate, especially in resource-constrained environments. [42] In a complex world, designers should emphasize strategy to motivate the pursuit of technology.[43] Appropriate innovation used here highlights the importance of a cost-benefit analysis. First, the anticipated benefit captures the acquisition community's ability to produce the desired capability to levy effects, ultimately in an effort to achieve an end state consistent with national strategic objectives. Second, state budgets constrain the anticipated cost allowed for RPA autonomy developments. In a recent statement on

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[40] Mark Draper, "Supervisory Control Interface Research for Next Generation UAS," 4. Then see Gloria L. Calhoun, et al., "Levels of Automation in Multi-UAV Control Allocation and Router Tasks," *American Institute of Aeronautics and Astronautics*, Unmanned Unlimited Conference, Seattle, Washington, 6-9 April 2009, 1. UAV is an acronym for Unmanned Air Vehicle. Finally see Christopher A. Miller and Raja Parasuraman, "Designing for Flexible Interaction Between Humans and Automation: Delegation Interfaces for Supervisory Control," *Human Factors*, 49 no 1, February 2007, 2.

[41] Thomas P. Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems*, Wiebe E Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: MIT Press, 1989), 51.

[42] Carl H. Builder. *The Icarus Syndrome*, 155,157,161. Builder discusses the USAF's cultural characteristic that accentuates a pursuit of technology.

[43] Carl H. Builder. *The Icarus Syndrome*, 256. In a resource constrained environment, Builder highlights the tension that exists with those entities that want to protect the pursuit of forces which have dominated the mission spectrum in the past. Also see Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, (Ithaca, NY: Cornell University Press, 1991), 259. Rosen emphasizes a strategy that prepares military innovations with respect to a management of uncertainty. He advocates this and a sound approach which a military service becomes increasingly cost constrained.

defense budget and priorities, the SecDEF made clear that he was planning a reform agenda that reduced military expenditures while funding RPA priorities.[44] In the cost-constrained environment of the 21st century, the USAF must emphasize a strategy-driven approach to technological innovation to maximize its ability to accomplish military objectives. This philosophy of acquisitions becomes the basis in which to improve communication and coordination of RPA autonomy objectives.

The next dimension considers the relevant organizational aspects used to acquire RPAs. The larger Air Force acquisition community represents a compilation of smaller organizational enclaves that attempt to advance the development of greater RPA autonomy. AFRL spearheads the USAF research and development (R&D) for autonomous technology developments for RPAs, along with universities and contractors associated with such efforts. This thesis focuses on two primary paths for technology insertion through USAF production. The first route includes the system program offices within Aeronautical Systems Center and the operational Air Force users organized through Air Combat Command (ACC). The second route to technology insertion includes Air Force Special Operational Command (AFSOC). Each chapter identifies drivers that would influence change in the working relationships. These drivers include both those originating from outside and within the acquisition community.

The Air Force Research Laboratory anticipates future development in technologies that help unmanned platforms increase in autonomy. Well planned innovation may help maximize platform effectiveness as well as multi-platform performance. The third dimension captures some important technology trends as the Air Force pursues this technological endeavor. The thesis does not present an exhaustive list. Rather, the technologies represent examples of what becomes important during the timeframe described within the chapter.

The final dimension considers the interface of the three aforementioned considerations: strategic focus, organizational construct, and technology drivers. This interface serves to inform the research effort about opportunities that could better position the acquisition community. The case study confines the scope of the recommendations to those considered most relevant to achieving the anticipated strategic end states. The

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[44] Robert M. Gates, *Statement on Department Budget and Efficiencies*, US Department of Defense, 1, 5.

recommendations also consider the implications for the next time period, thereby forecasting important topics to come in the following chapters. In some cases, the study infers strategic implications for the greater Air Force, beyond the acquisition community and its social interfaces.

Why Should Air Force Leaders Pursue Autonomy with a Strategic Focus?

The Air Force is at a crossroads in aeronautical development, as service leaders attempt to incorporate remotely piloted aircraft into doctrine and operational strategy. The crossroads represent the continued reliance upon manned platforms in near totality versus a heterogeneous fighting force comprised of manned and unmanned platforms working together. If the Air Force commits to the latter, autonomy innovations must improve efficiency and effectiveness. The Air Force encourages talented junior military personnel to invest their careers in unmanned platforms in current operations within Afghanistan and Iraq.[45] By fostering structural changes to its personnel system, offering command opportunities in the RPA community, and extending resources to RPA acquisitions, the service is signaling that this change will extend beyond the current conflicts.[46] As a result, the strategic vision is reinforced as innovation occurs, is tested, and is embraced by current and future leaders.

[45] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 252. Many of the features of organizational change that occur during peacetime are observed during the long wars in Afghanistan and Iraq. This observation suggests the ingredients for a lasting change. Then see Charles Dunlap Jr, "Making Revolutionary Changer: Airpower in COIN Today," *Parameters* Summer 2008, 57. Finally see Alan J. Vick et al., *Air Power in the New Counterinsurgency Era: The Strategic Importance of USAF Advisory and Assistance Missions*, (Santa Monica, CA: Rand Corporation, 2006), 111.
[46] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 252.

CHAPTER 1

RPAs TODAY

Introduction

This chapter characterizes the nature of Remotely Piloted Aircraft developments today. The material considered here serves as a baseline reference for the remaining chapters and assesses current RPA technology across each of the four dimensions used for analysis. To craft appropriate strategy that captures attributes applicable to how a warfighter might expect to use RPAs in today's aerial battlespace, the first section introduces a modified form of John Warden's key descriptors for system change. The strategy includes consideration of commander's intent with respect to RPA employment.

The analysis in the next major section introduces relevant organizational aspects within the RPA acquisition community. AFRL pushes innovation through this community in different ways. In its relationship with ASC, the Air Force Research Laboratory often operated in relative isolation to the other. At times, each pursued subsets of concepts that increased autonomy, even broaching some simplified versions of complex, multi-platform cooperative control concepts. Prior to the direction given by the Secretary of the Air Force, each of the two acquisition halves often generated custom solutions. The research and development arm of the Air Force has demonstrated its ability to pursue diverse aspects of autonomy in a seemingly haphazard manner.[1] Yet such developments are often sidelined when budgets fail to grow because the corresponding programs fail to designate outlets for technology transfer.

Alternatively, AFRL often succeeded in pushing innovation when the organization crafted a project aligned with Air Force Special Operations Command objectives. AFRL can introduce novel technology quickly to resolve urgent, near-term problems because of AFSOC's willingness to assume performance longevity risk in exchange for a quick introduction of a new capability.[2] For instance, AFSOC actively

[1] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011.
[2] Robert Smith and Caroline King, Air Force Research Laboratory (AFRL/RB), Interview, 18 February 2011.

sought help from R&D to develop a scheme that extended surveillance beyond line-of-sight operations though small RPAs.[3] Technology insertions that foster RPA autonomous development like this may work well with AFSOC, but require radically different approaches when working with ASC. This thesis attempts to highlight differences like this.

The third subsection focuses upon technical challenges that hinder RPAs in today's aerial battlespace. This section *spotlights* what functions really need automation at present. A delicate balance governs much of today's development. Rather than going into 'real' cockpits, many of today's pilots wrestle with the implications as 'virtual' RPA operators. A second major consideration pertains to common acquisition production considerations. How much of a previous design can one reasonably use? The acquisition work force needs to successfully balance today's costs as well as the perceived near and long-term benefits.

The final section considers some strategic opportunities that exist in today's environment as they influence the case study of the next timeframe. Specifically, multi-platform autonomy can potentially yield synergistic capabilities that exceed additive contributions of its members. The considerations of this section look at some initial efforts to convert some of today's assets to support research that fosters two or three RPAs working together into the aerial battlespace.

Strategic Focus

"A technological system," Thomas P. Hughes noted, "can be both a cause and an effect; it can shape or be shaped by society."[4] Militaries seek appropriate innovation because asymmetric technological advantage can contribute significantly to achieving victory. The USAF in particular pursues a complex combination of strategic and

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[3] Matthew T. Seibert, et al., "System Analysis and Prototyping for Single Operator Management of Multiple Unmanned Aerial Vehicles Operating Beyond Line of Sight," *Thesis*, AFIT/GAE/ENV/10-M01, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 2010, iv.
[4] Thomas P. Hughes, "Technical Momentum," in *Does Technology Drive History? : The Dilemma of Technological Determinism*, Merritt Roe Smith and Leo Marx, eds., (Cambridge, MA: MIT Press, 1994), 112. Hugh's observation can extend to entities within the society, such as the USAF as an institution.

technological advantage.[5] Accordingly, strategic imperatives shape the pursuit of autonomous RPA innovation, and vice versa. In order to understand the grand strategy that drives the USAF's current pursuit of RPAs, one needs to unravel a bit of history.

For decades, the Air Force displayed curiosity about unconventional machines. Although many nations tinkered with unmanned aircraft in the decades following WWI, the Germans demonstrated their military and political effects during WWII.[6] The US propagated the technology during the 1940s and 1950s by developing pilotless airplanes controlled by radio signals and using them as aerial targets.[7] As the aerial platforms' roles expanded to include reconnaissance, the term remotely piloted vehicle (RPV) emerged during the Vietnam era.[8] The term unmanned aerial vehicle (UAV) seems to have emerged for political reasons in the 1980s. The UAV acronym coincides with a desire to move away from assets associated with a failed war, coupled with generational improvements in technology capabilities.[9] On 15 December 2009, SecAF Michael Donley announced that all USAF personnel would use 'RPA' instead of 'UAV' to describe the platforms.[10] When asked for the motivation behind the latest change, the SecAF advocated that the new acronym better reflects the pilot's controlling role in the

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[5] Carl H. Builder, *The Icarus Syndrome*, (New Brunswick: NJ, Transaction Publishers, 2003), 161. Builder describes the USAF reverence for high tech solutions.

[6] Winston S. Churchill, *The Second World War, Volume V: Closing the Ring*, Mariner Books edition, (Boston, Houghton Mifflin Company, 1985), 201-05. The Germans asymmetric advantages in unmanned platforms extended from the employment of the Vergeltungswaffe-1 (V-1). Although inferior to the V-2 as a terror weapon, both weapons caused episodes of panic in the United Kingdom in 1944.

[7] Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age*, (Baltimore: The John Hopkins University Press, 1997), 41, 44. McDougall details how Werner Von Braun acted to ensure that his rocket team sought capture by the U.S. Army rather than the Soviets. His team became the nucleus of technology transfer to the US. McDougall proposes that the German V-1 represents the genesis to the American Cruise Missile program demonstrated in the 1980s. Also see UAV Forum, *What difference is there among the terms drone, RPV, UAV, ROA, RPA, and UAS?*, www.uavforum.com. For completeness, the acronym ROA stands for remotely operated aircraft.

[8] Thomas G. Mahnken, *Technology and the American Way of War Since 1945*, (New York: Columbia University Press, 2008), 113-14. The Air Force flew about 3500 sorties using several Remotely Piloted Vehicles, the most common of which was the Teledyne Ryan BQM-34 Firebee, alternatively known as the Lightning Bug. This inter-government program between the Central Intelligence Agency (CIA) and USAF was largely shunned by the Department of Defense following the Vietnam War; three follow on programs were scuttled, thus reflecting the lack of organizational embrace.

[9] Thomas G. Mahnken, *Technology and the American Way of War Since 1945*, 114.

[10] "Name Change For UAV Drones Approved. To Now Be Called Remote Piloted Aircraft. A Drone By Any Other Name," *Reuters*, 15 December 2009.

system.[11] USAF interest in these weapon systems multiplied in the last 15 years, and the framework developed by John Warden may inform this phenomenon.

According to Warden, painting the *Future Picture* represents the most important step in planning Grand Strategy.[12] He characterizes the *Future Picture* as a definition of where an organization wants to go within the anticipated operating environment.[13] With respect to the Air Force stance towards RPAs, the aviators retained control of the institution through their seniority.[14] As the dominate warfighter within the service, they possess the lions-share of authority. However, Carl Builder suggests that the hierarchy subverted their responsibility to organize, train, and equip forces in a manner that optimize efficiency and effectiveness to deliver effects in pursuit of strategic objectives. The admiration for the manned airplane clouded their judgment and privileged their support for manned aviation.[15] Yet, what caused the recent change in direction?

John Warden's *Future Picture* guides a questioning process that starts at a high level, followed by more detailed inquiry.[16] With respect to the recent acceptance of RPAs, the Air Force positioned itself to benefit from meaningful innovation sustainable for the long-term and to demonstrate relevance in current conflicts. The military currently fights in two long wars that have evolved through a range of intensity, the vast majority of which has become irregular warfare. While at war, the Air Force validates its strategic measures of effectiveness when the warfighters test approaches against enemy threats.[17] The long-term nature of these conflicts supplies repeated opportunities to test

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[11] "Name Change For UAV Drones Approved. To Now Be Called Remote Piloted Aircraft. A Drone By Any Other Name," *Reuters*, 15 December 2009.
[12] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 64.
[13] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63-64.
[14] Carl H. Builder, *The Icarus Syndrome*, 35.
[15] Carl H. Builder, *The Icarus Syndrome*, 34-35.
[16] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 65. Following an analogy derived from how architecture is used to query prospective customers in their desires for a future house construction, Warden proposes that an organization should start with high-level characterization questions. After learning more about customer intentions, architecture goes into increasing detail, emphasizing how they future occupants hope to use it. After this process and some time to draw, the architect will return with a layout proposal. In much the same way, one can understand what influences the force structure considerations. A sustained period of macro political and economic drivers are fostering a reconsideration of Air Force service priorities, weighing in on organize, train, and equip decisions.
[17] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, Cornell Studies in Security Affairs, (Ithaca, New York: Cornell University Press, 1991), 28, 30. In particular, RPAs minimize casualty risk, and permit extended persistence.

new military technologies in low intensity conflict. Additionally, the ability to test approaches in multiple environments adds concept robustness.[18] From the attributes realized during the questioning process, one can begin to characterize components about an organization that should become part of the *Future Picture*.

For the general case, Warden develops 12 key descriptors that characterize the grand strategy for an organization.[19] To demonstrate the relevance of the *Future Picture* that has driven the USAF strategy towards RPA development, this investigation develops two representative examples. The first pertains to new characteristics which the USAF wants its airmen to reflect.[20] Sustainable, long-term changes typically conducted in peacetime occur within the USAF during prolonged wars. Senior military officers create new career paths for younger officers to embrace, thereby promoting those accustomed to the new tasks.[21] Since the young airmen accept the new ways of war, they embrace the technological innovations that substantiate the strategic vision. Coupled with the social revolution that legitimizes the use of RPAs as a preferred way of war, today's Air Force will encounter a spending reduction unlike any encountered in recent times.[22]

The second of Warden's key descriptors relevant to this investigation combines organizational positioning and innovation in response to externally-driven budgetary contextual factors.[23] In a recent statement on defense department budget and priorities, Secretary of Defense Robert Gates clarified his intentions to implement a reform agenda that reduced military expenditures.[24] In the same statement, he clarified that he intended to increase resources available to RPA procurements and defended the ongoing organizational restructuring in favor of unmanned flight.[25] Understanding the national intent best positions airpower leaders to reassess airpower effectiveness and recommend modifications. This solution accentuates another inherent trait of Air Force culture – its

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[18] This refers to Afghanistan and Iraq Areas of Responsibilities (AORs).
[19] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.
[20] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 67.
[21] Rosen, Stephen Peter. *Winning the Next War: Innovation and the Modern Military*, 76.
[22] Robert M. Gates, *Statement on Department Budget and Efficiencies*, US Department of Defense, http://www.defense.gov, 6 January 2011, 1.
[23] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.
[24] Robert M. Gates, *Statement on Department Budget and Efficiencies*, 1.
[25] Robert M. Gates, *Statement on Department Budget and Efficiencies*, 5.

fascination with technology.[26] In the cost-constrained environment of the 21st Century, the USAF should emphasize a strategy-driven approach to technological innovation as the best source for advancement. This recommendation works against America's national strategic culture which demonstrates a natural indifference to threat-derived strategy.[27] In other words, the US will naturally prefer a capabilities-derived approach towards airpower development, even though it should favor a threat-based acquisition strategy instead. A capabilities-based approach to acquisition emphasizes a diverse range of development that could become useful in every possible contingency.[28] The US has demonstrated the ability to overcome airpower mismatches in past conflicts; however, this may not hold true in a cost-constrained future. The USAF should favor a threat-based acquisition strategy by emphasizing procurements in proportion to enemy courses of action and anticipated likelihood of occurrence.

Relevant Organizational Aspects

In order to set the stage for a discussion about the organizational aspects of the greater RPA acquisition community today, an understanding about the production portion of the organization becomes important. Two acquisition paths foster RPA production for the Air Force. The first implements the formal acquisition methodology.[29] The Aeronautical Systems Center uses the SPO organizational construct and a consortium of heterogeneous engineers with expertise from a variety of disciplines.[30] This combination welds a relationship between science and technology to develop RPAs.[31] Figure 3 (p. 89)

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[26] Carl H. Builder, *The Icarus Syndrome*, 155.
[27] Colin S. Gray, *Explorations in Strategy*, (Westport, CT: Praeger Publishers, 1998), 94-95.
[28] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, (Ithaca, NY: Cornell University Press, 1991), 244. Rosen presents two variants of capability-based acquisition. He recommends that a nation could avert significant costs by limiting the pursuit of some technologies to that of the R&D maturity levels. This thesis suggests that the prioritization of what to procure and to develop at some lower technical maturity level should emphasize a threat-derived strategic determination.
[29] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02*, 8 December 2008, 1.
[30] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion" In *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch, eds., (Cambridge, MA: MIT Press, 1989), 113-14. Heterogeneous engineers are defined as system builders that can assemble diverse elements into self-sustaining networks that successfully resist dissociation.
[31] Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts," in *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: MIT Press, 1989), 19. Pinch and Bijker's generalizations about the social construction extend to the organization that ASC has developed to create its RPA's, such as the MQ-1 and MQ-9. A

shows a simplified depiction of the current structure used by ASC. System design requirements for interfaces between aerial vehicle, ground segment, and payload components are managed internally by each SPO. Requirements represent the trade space for competing sub-systems and alternatives, thereby reflecting an understanding of the operating constraints and desired outcomes.[32] Often times, the difference between success and failure rests on the decisions of a well-disciplined cast of teammates within an integrated product team contained within a SPO.

If the SPO concept serves as a cost-effective venue to realize the automated cooperative control capabilities envisioned by the SecAF, familiarization with the current organization and some possible permutations becomes important. Figure 3 shows a simplified depiction of four independent SPOs, two of which are organizations within ASC. System design requirements (SDRs) for each platform-type are maintained within the respective SPO. ASC does not organize its systems engineering function to arbitrate collectively between SPO-controlled SDRs.[33] SPOs designing uniquely tailored platforms becomes the predictable result of such a community acquisition approach. In most cases, RPAs lack interchangeability between components and subcomponents with other platforms.[34] The design differences predictably drive an inability to sustain interaction between disparate platforms, since operations, doctrine, and functional capabilities are incompatible. The USAF will struggle and ultimately fail to realize the SecAF vision of automated cooperative control for joint multi-RPA applications if this acquisitions approach is sustained. The nature of this relation does not apply to the

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SPO is comprised of a diverse set of managers, engineers, and others that systematically produce the complex unmanned platforms.

[32] Stephen D. Chiabotti, *Heterogeneous Engineering and JPATS: Leadership, Logic, and Acquisition Requirements*, School of Advanced Air and Space Studies, Air University, Maxwell AFB, AL, Unpublished, 3, 10. Conclusions derived from the Joint Primary Aircraft Training System (JPATS) program extend to organizations that are tasked with increasingly sophisticated artifacts, including RPA platforms. The JPATs program succeeded. The preceding attempt, the T-46 program, failed to develop an aircraft trainer within cost and schedule requirements, leading to a cancellation of the contract.

[33] Klaus Wandland, Aeronautical Systems Center, Interview, 18 December 2009. Also note Major Brian Barker, Aeronautical Systems Center, Interview, 12 February 2010.

[34] "Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems," *GAO Reports* 09-520, 2.

second customer, as AFSOC does not hamstring itself to the same rigor of social construction when acquiring RPAs.[35]

A second path to technology insertion through AFSOC represents the "fast track." Because personnel associated with this dynamic organization emphasize quick innovations to address immediate warfighter needs, acquisitions process becomes less hierarchical in structure. The organization will assume risk in some aspects of a technology development in order to improvise a quick yet perhaps imperfect solution.[36] Within the Air Force, Joint Concept Technology Demonstrations (JCTD) and Advanced Technology Demonstrations (ATDs) provide organizational mechanisms to progress the maturity of ideas much faster than traditional acquisitions.[37] Other entities foster these "fast track" programs, both independently and in coordination with multiple Air Force organizations, such as the Air Force Office of Scientific Research (AFOSR), the Defense Advanced Research Projects Agency (DARPA), and the Central Intelligence Agency (CIA). Less restrictive organizational norms, coupled with an emphasis to find timely solutions to address immediate needs, accentuate RPA innovation that fosters autonomous development today.[38] What are the implications of the different organizational models used by the customers, ASC and AFSOC?

The former, ASC, creates the sustaining organizational muscles behind its projects for longevity. This organization professes a seemingly strict adherence to mechanisms that reinforce the socially constructed acquisitions approach. If the rules

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[35] Social construction describes technological innovation in which acquisition organizations learn what the warfighter wants to accomplish and then builds an artifact to promote that outcome. In this case, the SPOs within ASC practice programmatic social construction that emphasizes the platform-centric design at the expense of interoperability. The technological innovation drives incompatibility in this case. AFSOC practices a unique form of social construction that is less bound to formal programmatic practices, encouraging flexibility to modify platforms to satisfy immediate warfighter needs. For additional information about social construction, see the chapter contributed by Thomas P. Hughes, "The Evolution of Large Technological Systems" In *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds, (Cambridge, MA: Massachusetts Institute of Technology Press, 1987), 51-82.

[36] Robert Smith and Caroline King, Air Force Research Laboratory, Interview, 18 February2011.

[37] Defense Air University, "Science and Technology in the Acquisition Process," ACQ101, 4 April 2011, 54, 57.

[38] Robert L. Heilbroner, "Do Machines Make History?" in *Does Technology Drive History?,* Merritt Roe Smith and Leo Marx, eds., (Cambridge, MA: Massachusetts Institute of Technology, 1994), 59, 62. The observations about characteristics that accentuate innovative societies extend well to the RPA acquisitions community.

that pertain to SPOs hinder a certain type of innovation, the organization will suffer from its inability to change quickly. Such a dilemma exists when considering how to build platforms that works as part of a multi-RPA network, in which other organizations acquired the unmanned vehicles. The latter, AFSOC, acquires in a much less structured manner, often serving the USAF as the technological trailblazer for autonomous RPA technology enhancements.[39] AFSOC benefits those eager to introduce solutions that solve current and near-term problems. When reflecting on the progress made to date in the current low-intensity wars in Iraq and Afghanistan, most advances promote the march toward RPA autonomy.[40]

Technology Trend Observations

This section presents trends that impact the Air Force's pursuit of increased RPA autonomy today. This section does not capture every potential technical innovation required to realize RPA automation. Rather, it focuses on challenges that hinder RPAs in today's aerial battlespace. Since pilots dominate today's Air Force, technology trends tend to cater to their familiarity and preference.[41] It appeals to the aviator and technologist alike to expand upon what the service does well. Technologists must enable today's aviator venture into a world that permits the growth of RPAs, even at the expense of manned aircraft.

Technology Trends: Choosing What Functions to Automate

Some claim that the Air Force already conducts cooperative control with current RPA platforms. Today, coordinated control of RPA relies heavily on the human-in-the-

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[39] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011. Jacques reveals that technology advancements for RPA autonomy are developing at a pace that exceeds even the more adaptive operators. AFSOC is more rigorous in its design process than many of the commercial efforts that lead in introducing some technologies, but whose designs often lack battle worthy robustness. Also note Robert Smith and Caroline King, Air Force Research Laboratory, Interview, 18 February2011. Smith and King reveal how AFSOC has built key relationships within innovative organizations such as AFRL, thereby facilitating responsive design adaptation while on a shoe-string budget.

[40] Robert L. Heilbroner, "Do Machines Make History?" 56.

[41] Carl H. Builder, *The Icarus Syndrome*, 34-35, 163. Much like the influence that the adoption of the ballistic missile and space operations had on the USAF institution from the 1960s onwards, RPAs are broadening the meaning of airpower, as accommodated by the institution today. Expanding on Builder's concept, this thesis articulates the current approach to RPA insertion through co-opting the existing USAF power structure.

loop in order to perform almost all of the cognitive processes involved in operating multiple RPAs towards a common objective.[42] RPA operators are effectively tasked by a Coalition Air Operations Center (CAOC) to maneuver their RPAs within close proximity to other air assets in order to perform complementary tasks. In effect, the joint force has developed a way to mimic cooperatively-controlled assets that operate together to deliver a combined effect. In order to make the human more efficient at his or her task, numerous forms of automation can assist performance. In fact, technologists generate the strongest advocacy for increased automation when they multiply the effects produced by a given asset.[43] For example, consider a case in which two future RPAs use cooperative-control algorithms to optimally divide a search area, thereby reducing the amount of time needed to locate the intended target. The operator can verify the target and execute a munitions drop that destroys the target in less time when compared to the same applications without the automation. The flying community readily embraces such automation capabilities that improve mission effectiveness.

Technology Trends: Considering Reuse of Legacy Design

This subsection discusses the influence of reuse in legacy designs and how that might impact the vehicle designs intended for multi-RPA joint missions. The amount of legacy design reuse largely depends on the platform under consideration. Given the complexity and cost of the medium and large RPAs, reuse is important for the acquisition of these platforms.[44] The consideration becomes less important for small, lower cost RPAs.[45] Since the UAS flight plan envisions increasing sophistication to realize robust,

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[42] Lt. Col. Jeffery W. Eggers and Mark H. Draper, "Multi-UAV Control for Tactical Reconnaissance and Close Air Support Missions: Operator Perspectives and Design Challenges," Human Factors and Medicine Panel of the NATO Research and Technology Organization, 2006, 16. Also see Secretary of the Air Force Michael B. Donley, *Technology Horizons: A Vision for Air Force Science and Technology*, (Washington DC: Headquarters Air Force, 15 May 2010), i, ii.
[43] Colonel Michael Eggers, "Next Generation UCS: Concepts and Vectors," *AF/A2U ISR Innovations and UAS Task Force*, 16 March 2009, 3, 4, 9, 10. ISR represents intelligence, surveillance, and reconnaissance.
[44] Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems," *GAO Reports* 09-520, July 2009, 1, 4. In order to control the cost growth of numerous RPA development efforts, GAO recommends the use of greater commonality and advocating the opportunity for reuse through an open systems acquisitions approach. Some examples of medium RPAs include today's Predator and Reaper. The Global Hawk represents an example of a large RPA.
[45] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, (Washington DC: Headquarters, United States Air Force, 18 May 2009), 34-38. Most RPA platforms that are small in size are used as experimental demonstration platforms. Given the

multi-RPA missions and diverse RPA-types, one can assert that design reuse considerations would likely become more important to those RPA designs intended for use within a network.

For the more complicated RPA systems, design reuse options could save significant cost. If reuse options achieve system design requirements for the context of the new program, they represent a good reuse consideration.[46] The best examples for reuse typically include hardware components or modular devices. These devices are likely to perform a similar function for the RPA, regardless of whether the RPA flies alone or as part of a multi-RPA mission. Engineers must still ensure that any reuse components still interface satisfactorily as part of a new system.

Technology Trends: Maturing Reliable Software Modules

Developing software modules for complex RPA missions represents a tough challenge to the acquisitions community. In addition to integrating software algorithms that control an RPA platform, engineers must conceive ways to test algorithm performance. Although this may represent a large challenge, developmental programs have achieved a level of software complexity necessary to automate cooperative control algorithms for multiple RPAs.[47]

One possible way of addressing this complexity is to tailor a High Level Architecture (HLA), as developed by the DoD Modeling and Simulation Coordination Office.[48] Because of the coding complexity, software verification and validation for

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relatively low dollar amounts, organizations such as GAO look more towards the high priced platforms to make their points. Well-known small RPAs mentioned in the UAS Flight Plan are not covered in the aforementioned GAO report. Some examples of small RPAs include the Raven and Scan Eagle.

[46] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, (New York: Vintage, 2000), 122. In the design of the Atlas rockets used for the Inter-Continental Ballistic Missile (ICBM) program in the 1950s, Hughes captures some critical interactions that occur in the early stages of a program in which the lead engineer takes responsibility for deciding which system specifications should be optimized and which should reuse existing design expertise and experience. Hughes captures a negotiation process between component engineers to ensure a program appropriately balances risk of use design to achieve the design performance enhancements of the new program, while averting uncertainty in other facets of the design.

[47] Steve Rasmussen, Michael Holland, and Adam Bry, "COUNTER Cooperative Control Algorithms: Challenges and Lessons Learned," *AIAA-2008-6313,* AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008), 10. COUNTER is an AFRL sponsored program acronym that stands for Cooperative Operations in Urban Terrain.

[48] Modeling and Simulation Coordination Office, *High Level Architecture,* www.msco.mil.

automated cooperative control functionality could likely become a driving cost consideration in acquisitions.[49] To implement cooperative control among multiple RPAs, the software that manages the interfaces between multi-RPA network and platform-centric software becomes paramount. Tying back to the last section, imagine the challenge if an RPA SPO decides to reuse platform-centric software. High costs could originate from the difficulty in working through logical errors or incompatibilities imposed by the RPA architecture software. In addition, testing considerations may exceed the original scope of the software test program in working the interface issues, causing cost overruns and delays in schedule completion. If a construct such as HLA is used for the federated system as proposed here with multi-RPA autonomous cooperative control, then the acquisitions organization could capitalize on the compliance testing process established to ensure success between the distributed computer algorithms.[50]

Interestingly, arguments against the use of the HLA point to the fact that this construct stifles innovation.[51] Although engineers can provide examples in which standards unnecessarily restrict a project at hand, interoperability will require some shared software standards. One's perspective about software architectures may reflect one's service culture. The Army has mandated that RPA software remain compatible with STANG 4586, an international standard, whereas the Air Force continues to permit mission-specific software, as determined by the SPO or appropriate acquisition organization.[52] Recognizing the larger issue at stake to multi-platform RPA operations in the future, the UAS working group at the DoD level may attempt to sort out the software architecture approach.[53] An intervening body will likely become necessary as the desire to produce coordinated multi-RPA efforts increases.

Strategic Opportunities

[49] Howard E. McCurdy, *Faster Better Cheaper: Low-Cost Innovation in the US Space Program*, (Baltimore: The John Hopkins University Press, 2001), 27. The observations that McCurdy makes in linking cost and program complexity extend to software development. Interestingly, McCurdy goes a step further by linking these variables to project failure.
[50] Modeling and Simulation Coordination Office, *High Level Architecture,* www.msco.mil.
[51] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.
[52] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.
[53] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.

Strategic opportunities exist in today's developmental environment that may prove useful for advancing RPA-network innovation in the near future. Group-centric autonomy advances underlying technologies that foster a platform to interact as part of a group. While platform-centric autonomy developments dominate in priority, capabilities that contribute to multi-RPA cooperation will increase in importance.

In order to help humans control two RPAs simultaneously, uniquely tailored technical and social innovations are developed to achieve state-of-the-art functionality. For example, ASC recently produced the Multiple Aircraft Control (MAC) ground station prototype in order to enable a single operator to control multiple MQ-1 Predators or MQ-9 Reapers.[54] For today's multi-RPA approach, important functions such as the cooperative control interaction between RPAs rely on human decision making in lieu of automated algorithms. Cooperative control entails the pooling of capabilities delivered by a set of RPAs working together to achieve some common objective.[55] Potential performance gains could become available through advances in automation technology. For example, current airspace control automation lacks sufficient maturity.[56] The USAF acquisition community should prioritize which tasks would benefit the operator most if automated.

Conclusion

This chapter introduced the analysis structure pertaining to RPA development today. AFRL can leverage its unique position to play a major role in the development of RPAs. The strategy of RPA autonomy developments today seems fragmented in many respects. In order to ensure adequate buy-in from the pilots that control the service, most technological efforts develop platform-centric operator enhancements. Although examples exist that promote autonomous technological development, a comprehensive

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[54] Major Brian Barker, *Predator/Reaper: Thoughts on MAC*, Predator/Reaper Control Segment, Wright Patterson AFB, OH, 12 February 2010, 5.
[55] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," *AIAA-2004-6125*, AIAA 1st Intelligent Systems Technical Conference, Chicago, Illinois, 20-22 September 2004, 3.
[56] Lt. Col. Jeffery W. Eggers and Mark H. Draper, "Multi-UAV Control for Tactical Reconnaissance and Close Air Support Missions: Operator Perspectives and Design Challenges," 2. Also see Colonel Michael Eggers, "Next Generation UCS: Concepts and Vectors," 10-12.

strategic direction needs to focus technology development efforts.[57] The acquisition community emphasizes the delivery of capabilities in a seemingly haphazard way. Is the warfighter driving the pursuit of RPA autonomy? In the case of AFSOC, the answer appears to be yes. If anything, however, AFSOC aggravates the natural tendency of AFRL to introduce a suite of capabilities. The context of war does temper the evaluation of technology features, but major innovation during wartime invites higher risk and creates aversion against its use if wartime setbacks occur.[58] The recent directives that inhibit lethal application of force from RPAs tacitly corroborate this wartime principle.[59]

Future research needs a strategic objective to focus it. The irregular warfare (IW) context will continue to shape RPA autonomy developments. Anticipated reductions in USAF budgets will likely pressure the commitment to sustain the ongoing service conversion tilted in favor of RPAs. With the confluence of these factors, technologists will introduce the capability of multiple RPAs working together in a coordinated fashion in a combat zone.

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[57] Mark Draper, *AFRL/RHCI Roadmap Meeting*, Wright Patterson AFB, OH, 18 February 2011. Research objectives were binned into five focus areas, each promoting a larger objective of advanced supervisory control for networked multi-asset operation. This meeting clearly provides a good example of an attempt to link current and future programs towards a larger, overarching objective that is motivated by the SecAF and Air Force Chief of Staff.

[58] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 25.

[59] LTC Storm Savage, US Army/USMC COIN Center, "COIN Lessons Learned," *The Counter Insurgency Leaders' Workshop*, 28 October 2009, 19, 39. Storm presented a number of points that advocated for much restraint against lethal application of force. To airpower forces, he shows an aircraft and forecasts that the US will lose in Afghanistan if it responds conventionally to unconventional attacks.

CHAPTER 2

2011-2016 – MULTI-RPA NETWORKS IN THE AERIAL BATTLESPACE

Introduction

This chapter assesses near-term changes anticipated for the US Air Force's RPA acquisition community. Figure 1 (p. 87) indicates that the timeframe of this case study extends roughly five years into the future. The acquisition community begins to wrestle with implementing the SecAF vision for increased autonomy. While platform-centric advances in autonomous innovation mature, group-centric advances stagnate for most of the next five years. The preceding *Strategic Opportunities* section describes the preliminary efforts directed towards group-centric autonomy. Despite numerous obstacles, AFSOC achieves a major breakthrough by demonstrating collaborative control of two semi-autonomous RPAs within an IW aerial battlespace. As previously defined, RPAs demonstrate cooperative control when a set of these vehicles pool their capabilities in an effort to achieve some common objective. In order to substantiate this projection, one must understand how US policy interests motivate strategy regarding near-term threats.

States dominate the international system to promote interest.[1] States use power and prestige to influence this system in an effort to sustain policy objectives.[2] The United States has led this system since the end of WWII and enjoys the benefits derived from its position. The US must act according to prioritized threats from rising powers, most notably China, in order to sustain the Western-driven international order.[3] Robert Gilpin's hegemonic cycle theory extends to US policy to continue irregular warfare (IW) in Afghanistan, as developed in the *Strategic Focus* section of this chapter.[4] Military

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[1] Harry R. Yarger, *Strategy and the National Security Professional: Strategic Thinking and Strategy Formulation in the 21st Century*, (Westport, CT: Praeger Security International, 2008), 150.
[2] Robert Gilpin, *War & Change in World Politics*, (Cambridge, UK: Cambridge University Press, 1981), 25.
[3] Robert Gilpin, *War & Change in World Politics*, 207.
[4] Robert Gilpin, *War & Change in World Politics*, 6. Gilpin's hegemonic cycle theory captures an understanding of systematic change in international politics and war, thereby providing a framework for systematic analysis. The thesis extends these concepts to consider this particular IW case.

strategy links the political aims with various means to ensure future continuing advantage in the international system.[5] This consideration provides the relevant context to propose the military strategy for RPA acquisition in 2016.

John Warden's framework described in *Winning in Fast Time* outlines the anticipated strategic focus for RPAs within the IW context. This description will serve as the overarching *Future Picture* of where the organization intends to go within the IW operating environment.[6] Relevant key descriptors from Warden's recommended list inform Air Force decision-making to organize, train, and equip the organization for the IW fight with RPAs.[7] By describing how the use of RPAs may satisfy commander's intent in 2016, pertinent challenges surface about the organization's ability to acquire the improved capabilities.

The RPA acquisition community exhibits characteristics of divergence by 2016, as captured in the *Organization* subsection. One customer, AFSOC, serves as a trailblazer, seemingly eager to demonstrate new technologies. Yet, the fragile nature of such technological innovations highlights the need for a rigorous acquisition approach. As for the second customer, ASC becomes impaired in its ability to acquire future platforms. Although steeped in robust systematic processes for development, these organizational practices do not align well to acquire interoperable RPAs for Joint multi-vehicle missions. Although the customer lacks the technical understanding of multi-RPA networking, it often appears estranged to the USAF research arm, undermining their ability to ask for help. Despite the mandates from diverse leaders, such as the Secretary of Defense, the Secretary of the Air Force, other services, agencies external to the Department of Defense, and private companies, this customer seems unable to overcome bureaucratic inertia that maintains the traditional ways-of-doing-business.[8] Recognizing these limitations helps push the acquisitions community to focus upon critical lagging technologies for the increasingly autonomous RPA systems.

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[5] Everett Carl Dolman, *Pure Strategy: Power and Principle in the Space and Information Age*, (London: Frank Cass, 2005), 14.
[6] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 63-64.
[7] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.
[8] Paul A. Herbig and Hugh Kramer, "Innovation Inertia: The Power of the Installed Base," *Journal of Business and Industrial Marketing* 8, no. 3 (1993): 57.

Technologists will likely mature a large number of platform-centric technologies by 2016 that enhance autonomy, as captured in the *Technology Trends* subsection. One of the significant breakthroughs emerges in sense-and-avoid maturity for RPAs. Because AFSOC demonstrates multi-RPA operations in theater, the acquisitions community reflects on the tasks needed to produce the capability and articulates a prioritization of functions needed to diversify future group-centric applications. In addition to articulating what functions to automate, acquisition professionals convey guidance on diverse topics such as reuse opportunities and software maturity. With the emergence of group-centric applications, the acquisition community considers opportunities that could better position the acquisition community

The final section highlights emotional inhibitors to change. Awareness about the need to change the organizational relationships is inherently difficult. Many individuals within the system feel vested in supporting the status quo. Yet, cleavages between organizations in the USAF acquisitions construct emerge. Seizing the right moment for change becomes important, lest the RPA workforce falls into reorganization that personnel do not understand, and are thus unlikely to accept.

Strategic Focus

"States create international social, political, and economic arrangements in order to advance particular sets of interests."[9] Linking interests to relative power, Robert Gilpin offers a framework for thinking about war and change. This construct extends to US endeavors in irregular wars. Military leaders chose to organize, train, and equip the American warfighting organizations to smash a rival conventional foe.[10] Naturally, a rational enemy that chooses to fight the hegemon's superior forces would resort to irregular warfare tactics and try to exploit American norms to follow ethical and legal constraints. In order to achieve end states in anticipation of such circumstances, should the US increasingly hedge against such threats?

[9] Robert Gilpin, *War & Change in World Politics*, 25.
[10] *The US Army Marine Corps Counterinsurgency Field Manual*, (Chicago: The University of Chicago Press, 2007), li.

Irregular warfare captures a range of violent struggles between state and non-state actors as they compete for legitimacy to influence and lead relevant populations.[11] Context becomes unique for a specific IW conflict, such that slight nuances in approach to combat radically influence an actor's ability to achieve objectives.[12] This understanding further compounds during the evolving nature of the conflict, as dictated by the perceptions to risk and by responses to actions from belligerents, government forces, and the noncombatant majority populace. This section endorses US policy change that compensates for evolving contextual factors of irregular warfare to preserve the capability to win future wars. In the following subsections, Robert Gilpin's hegemonic cycle theory extends to considerations of the irregular warfare (IW) in Afghanistan. His framework helps link policy to strategy, thereby creating the context that motivates the use of RPAs through the military strategy in 2016. The understanding of these links inform the ability to develop the strategic focus for RPA acquisitions appropriate to IW, as developed later in the subsection.

Strategic Focus: Social Ordering

States dominate the international system in which they interact to promote diverse interests.[13] A variety of countervailing forces, such as those imposed by the market, organizational architecture, norms, and international law, combine to regulate behavior.[14] States thereby restrain their behavior to respect the interests of competing states.[15] Inter-state interactions often rely on a reductionist assumption that each state has the capacity to act as a unitary actor.[16] This assumption does not always apply. Within a state, disenfranchised parties may use violence to highlight governmental deficiency while

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[11] James D. Kiras, "Irregular Warfare," in *SAASS 644 Irregular Warfare Course Reader*, 1, tab 1, (Maxwell AFB, AL: Air University Press, 2011), 233. Dr. Kiras articulates general categories of IW, namely coup d' etat, terrorism, revolution, insurgency, and civil war. Because real world conflicts often have attributes of several categories, IW is best thought of as a continuum of potential characteristics.
[12] James D. Kiras, "Irregular Warfare," 268.
[13] Kenneth N. Waltz, *Theory of International Politics*, (Long Grove, IL: Waveland Press, 2010), 64, 65.
[14] Hedley Bull, *The Anarchical Society: A Study of Order in World Politics*, 3rd ed., (New York: Colombia University Press, 2002), 19. Bull develops contributors to world order as those patterns or dispositions of human activity that sustain elementary or primary goals of social life. These concepts of restraint readily extend to strategy formulation in preparation for irregular conflict.
[15] Kenneth N. Waltz, *Theory of International Politics*, 65.
[16] Kenneth N. Waltz, *Theory of International Politics*, 61.

coercing populations into accepting organizational change.[17] The nature of IW varies with environmental context, as do the effects experienced from the conflict. Spillover effects from such intra-state struggles can impact other states, and even the greater international social order. Sometimes non-state actors choose to operate from states that are too weak to resist the intruders, thereby ceding initiative to their parasitic guests.[18] Actions from such entities can levy threats that extend beyond a manageable nuisance.[19]

As the global hegemon today, the US uses its prestige and power to achieve its interests. The prestige derived by the US from asymmetric weapons often induces other states to comply with deterrence and compellence-based threats without kinetic action.[20] In Gilpin's context of hegemonic nuclear war, prestige was the primary motivator, more so than raw military power.[21] In today's low intensity conflicts, such as in Iraq and Afghanistan, power demonstrated across the full spectrum of warfare has become increasingly important to impose the nation's will.[22] The ability to retaliate affirms prestige that sustains stability within the international order.[23] The US derives a critical interest through its ability to tailor a military response to effectively impose national will, to fight future wars, and to achieve desired end states. The US intended to reassert this capability following the 9/11 attacks.

Strategic Focus: Today's Challenge to the Social Order

The nature of the irregular warfare in Afghanistan has changed when compared to the circumstances that motivated the original US response. The weak centralized government of Afghanistan hindered its ability to act on behalf its people and further

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[17] James D. Kiras, "Irregular Warfare," 226.
[18] David Kilcullen, *The Accidental Guerrilla: Fighting Small Wars in the Midst of a Big One*, (Oxford, NY: Oxford University Press, 2009), xiv.
[19] Audrey Kurth Cronin, *How Terrorism Ends: Understanding the Decline and Demise of Terrorist Campaigns*, (Princeton, NJ: Princeton University Press, 2009), 197.
[20] Robert A. Pape, *Bombing to Win: Air Power and Coercion in War*, (Ithaca, NY: Cornell University Press, 1996), 12-13. Deterrence by punishment invokes an implied threat that attempts to convince a state not to do something. Compellence uses punishment to convince an enemy to stop some specific course of action.
[21] Robert Gilpin, *War & Change in World Politics*, 31.
[22] David Kilcullen, *The Accidental Guerrilla: Fighting Small Wars in the Midst of a Big One*, 106. Kilcullen focuses the portion of the full-spectrum appropriate to the low intensity conflict. These considerations are appropriate for the full-spectrum of warfare, to include conventional applications.
[23] Audrey Kurth Cronin, *How Terrorism Ends: Understanding the Decline and Demise of Terrorist Campaigns*, 120.

aggravated its claim to legitimacy with acts of corruption and incompetence.[24] The US efforts to reinforce the creation of a legitimate government through the use of kinetic action have produced marginal returns at best.[25] As the Afghanistan government limps along, the US must evaluate whether the anticipated benefits for the effort are worth the future costs.

Robert Gilpin observed that hegemonic decline typically follows increasing outlays to maintain its current course of international stability.[26] The US has come to appreciate the expense of bankrolling a counterinsurgency fight. The needs of the conflict require unique skill sets and relationships within each of the 34 provinces.[27] Local leaders may join the Afghanistan government or its competing Taliban rival, reflecting an uncertain outcome.[28] Interestingly, several well-known authors have declared how hyperactive US conventional response for counter insurgency plays into a strategy that exhausts the retaliator, exposing it to overreach.[29]

Strategic Focus: Why the US Will Choose to Stay in Afghanistan?

Robert Gilpin argued that a leading state will not change its approach unless pressed to make concessions to a rising power with a credible force.[30] As the US has labored to reinforce the beleaguered Afghan government, the Chinese have pursued economic opportunities in the region. In particular, Afghanistan's mineral resources could prove extremely lucrative.[31] As such, if the US were to withdraw, the international

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[24] Seth Jones, *In the Graveyard of Empires: America's War in Afghanistan*, (New York: W.W. Norton & Company, 2009), 183-84, 201.

[25] John Jogerst, "Preparing for Irregular Warfare: The Future Ain't What it Used to Be," in *SAASS 644 Irregular Warfare Course Reader*, 2, tab 3, (Maxwell AFB, AL: Air University Press, 2011), 3. Jogerst refrains from evaluating the US approach in this particular section, but does a good job characterizing how the Karzai central government was set up. The judgment about its performance is that of the author of this essay.

[26] Robert Gilpin, *War & Change in World Politics*, 168.

[27] Antonio Giustozzi, *Decoding the New Taliban: Insights from the Afghan Field*, 2, in *Decoding the New Taliban: Insights from the Afghan Field*, Antonio Giustozzi, ed., (New York: Columbia University Press, 2009), 2.

[28] Antonio Giustozzi, *Decoding the New Taliban: Insights from the Afghan Field*, 298.

[29] David Kilcullen, *The Accidental Guerrilla: Fighting Small Wars in the Midst of a Big One*, 276. Also see Audrey Kurth Cronin, *How Terrorism Ends: Understanding the Decline and Demise of Terrorist Campaigns*, 198. Killcullen and Cronin formulate their conclusions about state overreach while critiquing the heavy US counter terrorism response. In comparison, the US efforts to pay for the counterinsurgency magnifies these spend rates dramatically, and for a long duration.

[30] Robert Gilpin, *War & Change in World Politics*, 207.

[31] Gordon G. Chang, "The Taliban: World's Next Minerals Superpower," www.forbes.com, 16 June 2010. This topic was discussed in various SAASS seminars.

order would suffer from two shocks. The emboldened Taliban would likely topple the Karzai government in a way similar to the South Vietnamese government's capitulation to the North in 1975.[32] US prestige would suffer by its inability to wield the military instrument to deter or compel to stave off future enemy action. In addition, China would likely move to secure its assets in Afghanistan. They would craft their interests narrowly to preserve their economic interest.[33] Regardless of whatever chaos occurs in the rest of the Afghanistan, the international community will note China's success in preserving its interests and the US inability to preserve its governmental creation, to the detriment of the world order.

Gilpin offers three reordering approaches that could become relevant to obviate such a challenge, while providing an avenue for the US to preserve its interest in demonstrating a credible IW capacity. One option suggests that a declining hegemon should pursue a negotiated settlement.[34] This proposal does not work well in Afghanistan today, as countries involved in international stabilization efforts do not really have a strong self-interest there. A second option has the declining hegemon pursue a series of limited wars against the rising powers.[35] This idea does not remedy the budget constraints already aggravated by extended war, especially with the rising power as the primary debt holder. A third option suggests that the hegemon disengage from some international obligations in order to retain the ability to defend others.[36] Given the threat to international stability posed by Chinese actions that hedge against American abandonment, the US will likely retrench its actions to align with its interest here. The US will foster Afghanistan government legitimacy to enable the coalition's withdrawal without host nation collapse. With two significant interests at stake, the context motivates the USAF RPA acquisition strategy to support the military strategy in 2016.

Strategic Focus: Warden's Guide for the RPA Context in 2016

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[32] R. W. Komer, "Bureaucracy Does Its Thing: Institutional Constraints on US-GVN Performance in Vietnam," in SAASS 644 *Irregular Warfare Course Reader*, 2, tab 4, (Maxwell AFB: Air University Press, 2011), vi.
[33] It is reasonable to assume China would insert military forces to sustain their national investments.
[34] Robert Gilpin, *War & Change in World Politics*, 208.
[35] Robert Gilpin, *War & Change in World Politics*, 216.
[36] Robert Gilpin, *War & Change in World Politics*, 192.

Given sustained operations in Afghanistan, the USAF should continue to focus its near-term efforts to suppress the IW conflict with the support of its RPA fleet. Thus, the *Future Picture* facilitates a USAF RPA acquisitions strategy that begins to introduce automated collaborative RPAs in the battle zone by 2016.[37] With the *Future Picture* characterized, Warden's framework for crafting strategy turns to capturing attributes that anticipate how a warfighter might expect to use RPA's in the near-future battlespace.[38] Since the counter insurgency (COIN) operation will continue in Afghanistan, engineers will design two RPAs that cooperate autonomously in a non-kinetic manner.[39] Warden shows how to break down aspects of the *Future Picture* using a questioning process that starts at a high-level before going into more detail.[40] For instance, within some shared restricted air space, one RPA will locate a surveillance point-of-interest on the ground. Based on information supplied from the first RPA, the second vehicle working collaboratively would then determine and position itself to enhance the geolocation precision or monitor another position which is tactically relevant to the first one, thereby minimizing uncertainty. A single primary operator will manage the engagement. Through demonstration, aviators gain confidence in the automated techniques offered through RPA developments.

Warden recommends that an organization articulate relevant key descriptors to detail the grand strategy for the acquisition of RPA automation for the IW fight.[41] One important descriptor becomes that of fostering innovation.[42] AFSOC represents the more cavalier customer, thereby fulfilling the role of the second descriptor of interest –

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[37] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 64.

[38] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63-64.

[39] The cooperative control algorithms differentiate this future effort from the group-centric activities in 2011that merely mimic cooperatively-controlled activity to deliver a combined effect. The two RPAs in this scenario perform autonomous functions for themselves to the mission objectives of the group. See Hui-Min Huang, Elena Messina, and James Albus, "Autonomy Levels for Unmanned Systems (ALFUS) Framework," *NIST Special Publication 1011-II-1.0*, December 2007, 16. Huang advises that RPAs need to sense, perceive, analyze, communicate, plan, decide, and execute an assigned objective on its own to achieve autonomy. Technically, one would characterize this demonstration as semi-autonomous group behavior between two RPAs, realizing only some portion of Huang's characterization of autonomy.

[40] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 65.

[41] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.

[42] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 67.

ownership.[43] The customer will charter a special integrated product team to propose a tailored acquisition strategy. AFSOC will represent a lean organization, comprised of pertinent engineers and program managers to complete the task at hand. AFRL assigns the right subject matter experts (SMEs) to advise the integrated product team on technical matters, to include aspects of group-centric RPA autonomy. The special integrated project team manages all system design requirements to support AFSOC customer design requirements. With the goal of the case study introduced and the micro-level execution strategy sketched, the impact to the acquisition organizations need consideration.

Relevant Organizational Aspects

The Air Force wants to pursue technology advances that increase RPA autonomy and improve mission effectiveness. Nevertheless, a tacit rift separates entities within the Air Force acquisition effort. AFSOC often introduces immediate technological problems for their warfighters in theater, well-suited for those organizations like AFRL that want to supply technological solutions. Innovations that enable improvements in RPA autonomy are readily embraced, often without the rigorous testing that ensures performance longevity.[44] The warfighters eagerly pursue the use of innovations that help their situational awareness in the current IW campaigns.[45] For instance, AFSOC may seek to incorporate approaches to streamline systems engineering for rapid development, or modify a scheme that enables extended surveillance provided by small RPAs beyond line of sight operations.[46] A technology savvy end user, coupled with a flexible organization in the form of IPTs, and supported by idea generation through AFRL, all combine to push the state-of-the-art.

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[43] John A. Warden III and Leland A. Russell, *Winning in Fast Time,* 67.

[44] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011. Also note Robert Smith and Caroline King, Air Force Research Laboratory, Interview, 18 February 2011. AFSOC does test its platforms to ensure that new technologies do not endanger the warfighting users.

[45] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011.

[46] Abbott Laird, et al., "Systems Engineering for Transition of the Fleeting Target Technology Demonstrator," *Thesis*, AFIT/GAE/ENY/07-M03, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 2007, v. Also see Matthew T. Seibert, et al., "System Analysis and Prototyping for Single Operator Management of Multiple Unmanned Aerial Vehicles Operating Beyond Line of Sight," *Thesis,* AFIT/GAE/ENV/10-M01, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 2010, iv.

AFSOC's ability to introduce two semi-autonomous RPA working collaboratively within the aerial battlespace reflects the flexibility of its organization. Others benefits from the AFSOC trailblazing effort. For instance, one AFSOC program successfully stretched the bounds of the digital data link which other users adopt.[47] The rest of the USAF benefits because ASC will likely adopt these lessons that prove successful. This example represents one of many advances that AFSOC has produced and shared.

A noticeable difference exists when considering the AFRL and AFSOC working relation compared to AFRL and ASC. Two informal *camps* demonstrate developments in autonomy, in efforts relatively independent of each other. These camps do not reflect any formal organizational arrangement. The end user community, to include ACC and ASC's system program offices, comprises the first camp. The corresponding research and development organizations, including AFRL, aligned university researchers, and contractors that work with and for these entities, make up the second camp. The camps have not reached consensus for an approach to best realize cooperative multi-RPAs today, let alone in 2016. This problem also applies to many RPA technology developments.

Organization: The Production Oriented Half of the RPA Acquisition Community

The first camp associates with the end user community and includes system program offices, typically within ASC, and operational Air Force users, usually in ACC. The DARPA-funded programs that eventually spin-off to the Air Force would also fall within this camp. The MQ-1 Predator represents a program that originated with DARPA and has transitioned to ASC "ownership." DARPA also manages the Unmanned Combat Aerial Vehicle (UCAV) program. Whether or not they spin-off control of the UCAV program to the Air Force remains to be seen.

ASC sometimes displays the ability to generate "improvements" as ingenious afterthoughts, certainly not the primary focus. For instance, Boeing used one of its final X-45 UCAV flight tests to demonstrate cooperative control between two RPAs

[47] Robert Smith and Caroline King, Air Force Research Laboratory, Interview, 18 February 2011. Smith and King told of an experimentally developed AFSOC program that introduced digital data link upgrades. The successful demonstrations stretched the performance capability. Other users adopted the advanced concepts.

responding to a simulated pop-up threat.[48] The ground segment element team recognized that the UCAV platforms possessed extra computational capacity at the ground station, allowing the Boeing engineers to construct a relatively simple centralized automated cooperative-control algorithm. Excess communication bandwidth capacity between ground station and each UCAV enabled execution of the experiment in a flight test. Additionally, the algorithm discussed here was tailored for a two-ship implementation, so the algorithms may not scale easily to larger applications.

The lack of an articulated vision about multi-RPA autonomy contributes to some of the manpower overhead required to field an RPA system. When a program office decides to add additional functions in today's design environment, the approach to integration could lack a cohesive system integration and internal system monitoring if the original design lacks adequate modularity. Modularity refers to the ability to interchange particular subcomponents because they contain standardized interfaces with the larger system. The unintended side effect of unanticipated growth in functionality could involve an additional person to monitor the function. This phenomenon may inform why Predator and Global Hawk require 168 and 300 personnel, respectfully, for each combat air patrol.[49] Policy makers have good reason for skepticism when considering the rhetoric of cost savings from RPAs in today's acquisition environment. The USAF, therefore, should modify its traditional approach described here to realize the SecAF's multi-RPA vision and reduce manpower costs.

Organization: Radical Innovation Needs Leadership to Rise From Within the Labs

Prior to the recent push from high within the Air Force hierarchy to foster autonomy research, the second camp remains disconnected from the issues plaguing the aforementioned camp.[50] For clarity, this informal grouping includes government-run

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[48] Bill Barksdale and Chris Haddox, "Boeing's X-45As Reach 50th Flight with First Simulated Combat Mission," *Boeing Corporation*, 14 February 2005, http://www.boeing.com.
[49] Greg Zacharias and Mark Maybury, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, Washington DC: Scientific Advisory Board, 7 July 2010, 16.
[50] Michael B. Donley, *Technology Horizons: A Vision for Air Force Science and Technology*, Washington DC: Headquarters, United States Air Force, 15 May 2010, 59, 65-66. Then see Greg Zacharias and Mark Maybury, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, 7. Finally see Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, Washington DC: Headquarters, United States Air Force. 18 May 2009, 31, 42.

organizations, such as the Air Force Research Laboratory as well as university programs and contractors associated with various R&D entities. Often lacking direction, the R&D community develops a vast toolbox of alternatives because the scientists do not really know which parameters will become important for future applications. Technologists ultimately select some combination of these enabling capabilities for a program's execution, as appropriate. Applications that facilitate RPA group autonomy are diverse. Examples of such work include multi-vehicle control codes,[51] estimating uncertainty sources,[52] time lag sources,[53] hardware implications,[54] and parameters for cooperative optimization.[55] The complexity and sophistication of research in many of these efforts could go unutilized without a coordinated RPA development framework.[56]

In the absence of a coordinated organization that bridges to the production system program offices, the social construction that produces multi-RPA system autonomy may not mature.[57] In such a case, technologists spend USAF R&D dollars to develop individual technical breakthroughs that program offices never use. The USAF pays a premium to develop technology in a haphazard manner.[58] Breakthroughs often lead to additional ideas for innovation. The key to maximizing the return for R&D money reflects that the USAF does not control the innovation. Instead, an articulated vision from the customer and its production entities helps the R&D engineers to seek relevancy for their innovation before the effort is expended in a general search.

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[51] Stephen R. Dixon, Christopher D. Wickens, and Dervon Chang, "Mission Control of Multiple Unmanned Aerial Vehicles: A Workload Analysis," *Human Factors* 47, no. 3 (Fall 2005), 479.
[52] Meir Pachter, Nicola Ceccarelli, and Phillip Chandler, "Estimating MAV's Heading and the Wind Speed and Direction Using GPS, Inertial and Air Speed Measurements," *AIAA-2008-6311*, AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008, 1. MAV is an AFRL sponsored program acronym that stands for Micro Air Vehicle.
[53] Steve Rasmussen, Michael Holland, and Adam Bry, "COUNTER Cooperative Control Algorithms: Challenges and Lessons Learned," *AIAA-2008-6313*, AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008), 10.
[54] Shannon M. Farrell, "Waypoint Generation Based on Sensor Aimpoint," *Thesis*, AFIT/GAE/ENV/09-M01, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, March 2009, iv.
[55] Tyler H. Summers, Maruthi R. Akella and Mark J. Mears, "Coordinated Standoff Tracking of Moving Targets: Control Laws and Information Architectures," *Journal of Guidance, Control and Dynamics* 32, no. 1 (2009): 63-64.
[56] Mark Draper, Air Force Research Laboratory, Interview, 23 August 2010. Also note David Jacques, Air Force Institute of Technology, Interview, 16 February 2011.
[57] Thomas P. Hughes, "The Evolution of Large Technological Systems" in *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: Massachusetts Institute of Technology Press, 1987), 52.
[58] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011.

Technology Trend Observations

Significant technology drivers impact the Air Force's ongoing pursuit of increased RPA autonomy. A large number of technologies that enhance platform-centric autonomy mature in the next several years. The airspace management regimes, such as the Federal Aviation Administration (FAA), for example, will likely accept a workable sense-and-avoid technology if feasible. Developments during this timeframe accentuate the need to recognize two distinct capabilities, as presented in Figure 2 (p. 88). The first capability permits quick, adaptive responses. Platforms integrating this design concept thwart the enemy's spontaneous initiative. The second capability maximizes strategic mission execution. In many ways, R&D mirrors those approaches from the preceding period, as discussed in Chapter 1.

Technology Trends: Sense and Avoid Breakthrough

This section briefly presents the acceptance of a developed sense-and-avoid technology to permit two RPAs to maneuver more autonomously in the aerial battlespace. International Civil Aviation Organization (ICAO) and FAA flight rules in 2011 restrict RPA operations. The *sense and avoid* between manned and unmanned aircraft represents the most controversial aspect of the restrictions.[59] The organizations that eventually introduce multiple RPAs into the aerial battlespace will need to understand the sense-and-avoid technology to provide meaningful judgment about its maturity.[60] Any failure of this technology to perform as advertised while in operation could stifle additional progress for years. Other issues, such as communication frequency utilization, represent socially constructed barriers that hurt RPA access to flight.[61] This consideration requires political agreement to permit the possibility of a standard to emerge. The acquisition community's heterogeneous engineers should monitor the political deliberations about this technology and look for ways to advocate for policy that

[59] Claude Le Tallec, "VFR General Aviation Aircraft and UAV Flight Deconfliction," *Aerospace Science & Technology* 9, no. 6 (September 2007): 495. The acronym VFR stands for Visual Flight Rules.
[60] David Jacques, Air Force Research Laboratory, Interview, 16 February 2011.
[61] David C. Gross and Jeffrey K. Hill, "COUNTER Flight Demonstrations," *AIAA-2008-6314*, AIAA Guidance, Navigation, and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008, 7.

encourages innovation. Sense-and-avoid technology becomes particularly important for any future considerations that seek close proximity cooperative applications, to include cooperatively-controlled RPA formations.

Technology Trends: Choosing What Functions to Automate For Group Applications

The first significant observation relevant to cooperative control of multi-RPA missions pertains to the increased interest and research developments to automate aspects of an RPA mission. For instance, work completed in the 2004 timeframe captures the noticeable effects of work overload as pilots handle two RPAs simultaneously.[62] The next seven years, however, uncovered advances in automated functions of routine tasks which have significantly improved mission effectiveness. Future unmanned aircraft system planners will need to prioritize a compatible subset of functional automations for cooperative control of multi-RPA missions.

The prioritization of automation processes will occur during two broad steps. First, the user community will determine the desired capability objective for automation, thereby tempering the scope of work based on the perceived maturity of the technology. The sorting process used to rank cooperative control automations can mirror standard systems engineering practices in use today. For example, as the customer, ACC works with AFRL to derive technology Requests For Information (RFIs).[63] After working with industry partners to define feasible technologies that satisfy the user-based concepts, SPOs use Analysis of Alternatives (AoA) to assess the maturity of proposed concepts.[64] Second, the acquisition community communicates user requirements with a Capability Development Document (CDD).[65] Among other things, this document articulates a Concept of Operations (CONOP) that describes how the user community wants to

[62] Stephen R. Dixon, Christopher D. Wickens, and Dervon Chang, "Mission Control of Multiple Unmanned Aerial Vehicles: A Workload Analysis," 479.
[63] ACC/A8, *MQ-X Unmanned Aerial System (UAS) Functional Solutions Analysis (FSA) Report*, 9 February 2009, 3. The process demonstrated for the MQ-X represents a typical conceptual analysis in preparation for an RPA acquisition by ACC through ASC.
[64] ACC/A8, *MQ-X Unmanned Aerial System (UAS) Functional Solutions Analysis (FSA) Report*, 2.
[65] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02,* 8 December 2008, 19. The CDD builds on the Initial Capabilities Document (ICD) and provides the detailed operational performance parameters necessary to complete the proposed design.

conduct multi-RPA missions. The production entities within ACS then become responsible for producing system design requirements to achieve missions.

A second automation theme addresses how an acquisition program should prioritize tasks performed by algorithm instead of by human. Advocates for cautious pursuit of autonomous technology development and insertion call for categorizing all group-centric tasks into one of two broad categories, control path tasks and mission path tasks.[66] Control path tasks are those that ensure the RPAs are oriented in the right place at the desired time.[67] These tasks represent excellent targets for automation, such as alternate transit planning and execution from point A to B in lieu of an emerging pop-up threat. Mission path tasks are those that are performed to achieve and evaluate the operator's objective.[68] Examples of mission path tasks include near real-time imagery evaluation or the choice to perform a verification fly-by in order to observe target destruction. Technologists can automate some mission-related tasks. However, human operators should continue to play a significant role in these tasks into the near future. The user community may very well prohibit technically viable advancements with RPA automation purely because senior decision makers need to gain trust and assurance with demonstrated performance.[69] With this insight in mind, the acquisition community will need to emphasize a procurement strategy that phases in the amount of automations that match user community expectations.

Technology Trends: Reuse of Legacy Design for Platforms Intended for Group Applications

Previous design decisions could act as constraints in future engineering considerations. Consider the case in which a new, complex system does not completely

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[66] Major Brian Barker, "Predator/Reaper: Thoughts on MAC", *Predator/Reaper Control Segment*, Wright Patterson AFB, OH, 12 February 2010, 4. Barker advocates for three task categorizations specific to the Multi-RPA control of the MQ-1 Predators or MQ-9 Reapers, to include 1) transit manager, 2) benign ISR manager, and 3) tactical mission controller. The text located above in the essay recognizes terminology that could apply to a broader categorization of RPAs. Control path tasks encompass Barker's first two task groupings.

[67] Major Brian Barker, "Predator/Reaper: Thoughts on MAC", 4. Control path tasks encompass two task categorizations previously proposed by Barker.

[68] Major Brian Barker, "Predator/Reaper: Thoughts on MAC", 4.

[69] Colonel Michael Eggers, "Next Generation UCS: Concepts and Vectors," *AF/A2U ISR Innovations and UAS Task Force*, 16 March 2009, 9, 10.

discard all elements of old design. In fact, engineers often add a subset of new features and functions to an appropriate combination of proven sub-assemblies, referred to as legacy design. The reuse of legacy design reflects the reality of constrained budgets and conservative risk taking.[70] Sometimes this works well, as when Boeing used one of its final X-45 UCAV flight tests to demonstrate cooperative control between two RPAs responding to a simulated pop-up threat.[71] Cooperative-control algorithms used in this 2005 proof-of-concept experiment were simple enough to use excess computational capacity. However, a separate 2009 R&D cooperative control flight test demonstrates the impact when RPAs have insufficient flight processing onboard the air platform. In this case, competing legacy algorithms coded for use on the flight processors forced engineers to simplify the cooperative control implementation to the point that it degraded mission performance.[72] The observation should motivate early efforts to preserve aspects critical for the more expensive medium-to-large multi-RPA applications.

Technology Trends: Maturing Reliable Software Modules for Group-Centric Applications

Implementing automated RPA cooperative control and formations also involves a need to mature the theory and required techniques. Despite the limited exposure of demonstrating automated cooperative control on R&D demonstrations, AFRL researchers are reasonably confident in their ability to codify such concepts based on experience in extended simulation and experimental flight tests.[73] To familiarize the reader with broad categories of potential software automation, the modules include vehicle path planning, optimal sensing geometry, decentralized control law design, and information

[70] Donald MacKenzie, "Missile Accuracy: A Case Study in the Social Processes of Technological change," In *The Social Construction of Technological Systems*, edited by Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch, (Cambridge, MA: MIT Press, 1987), 202.
[71] Bill Barksdale and Chris Haddox, "Boeing's X-45As Reach 50th Flight with First Simulated Combat Mission."
[72] Steve Rasmussen, Michael Holland, and Adam Bry, "COUNTER Cooperative Control Algorithms: Challenges and Lessons Learned," 2.
[73] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011. Feitshans was involved in coding the cooperative control software for simulation purposes. Also see David C. Gross and Jeffrey K. Hill, "COUNTER Flight Demonstrations," 1.

architectures.[74] Engineers need a plan to monitor the verification and validation of the integrated system software when adopting the concepts into the acquisition.

Strategic Opportunities

Risk of disassociation exists in cases where the scope of technical functionality exceeds the scope of design authority.[75] Changing the organizational structure is challenging, even when needed to succeed. RPA organizational cornerstones, such as platform-centric RPA SPOs within ASC, should only attempt modification with great care to transform it gradually and justifiably.[76] Figure 3 (p. 89) introduced a simplified depiction of four independent SPOs, two of which are organizations within ASC. Each SPO maintains system design requirements for each platform it acquires. ASC does not organize its systems engineering function to collectively arbitrate between SPOs.[77] Predictably, many platforms are uniquely tailored since engineers often do not design RPAs with interchangeable subcomponents.[78] Such an acquisition approach will likely hinder the SecAF's vision for automated joint multi-RPA applications.

Strategic Opportunities: Drivers External to the USAF Acquisition Community

External drivers inform the acquisition workforce about technology opportunities that could prove useful for RPA automation. First, AFRL identifies those projects that are considered top priority, as driven by technical needs of important organizational customers.[79] Designated as *Flagship*, the AFRL commander personally assesses these

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[74] Tyler H. Summers, Maruthi R. Akella and Mark J. Mears, "Coordinated Standoff Tracking of Moving Targets: Control Laws and Information Architectures," 56.

[75] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion" In *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch, eds., (Cambridge, MA: MIT Press, 1989), 114, 124.

[76] Michael Callon, "Society in the Making," In *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: Massachusetts Institute of Technology Press, 1987), 89.

[77] Klaus Wandland, Aeronautical Systems Center, Interview, 18 December 2009. Also note Major Brian Barker, Aeronautical Systems Center, Interview, 12 February 2010.

[78] "Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems," *GAO Reports* 09-520, July 2009, 2. The GAO is the General Accounting Office.

[79] Doug Meador, Air Force Research Laboratory, Interview, 17 February 2011.

programs.[80] The laboratory's system engineers generate requirements and Key Performance Parameters (KPPs) for them, assuring the *Flagships* satisfy customer needs.[81] KPPs serve as the critical metrics upon which to evaluate the capability of the artifact.[82] As a result, these metrics heavily influence the goals of an organization. *Flagships* reflect a keen interest from a customer, as these programs already possess funding for further development beyond R&D maturity levels.[83]

As a second important program stratification, programs identified as *capability concepts* produce capabilities deemed consistent with customer needs.[84] These programs receive a high level of attention from organizational systems engineers in terms of defining user requirements and KPPs.[85] Designated customers are intimately involved in these programs as well.[86] AFRL further recognizes programs that could become *capability concept*s, but lack the maturity to warrant such distinction at present.[87] AFRL also seeks guidance from customers with respect to its budget recommendations to Congress.[88]

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80 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, AFRL Memorandum, Wright Patterson AFB, OH, July 2010, Attachment 3, 2.

81 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, AFRL Memorandum, Wright Patterson AFB, OH, July 2010, Attachment 3, 2.

82 John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02,* 8 December 2008, 20.

83 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 2. Also see John C. Mankins, "Technology Readiness Levels," A White Paper, Office of Space Access and Technology, 6 April 1995, http://www.nasa.gov. Mankins identifies nine technology readiness levels (TRLs) which provide a basis to assess the maturity of a particular technology. AFRL typically develops technologies to TRL 1 (Basic principles observed and reported), 2 (Technology concept and/or application formulated), or 3 (Analytical and experimental critical function and/or characteristic proof-of-concept). Funding designated for additional maturity seeks to advance its readiness even further, perhaps to the component validation or even prototype demonstration TRLs.

84 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 1.

85 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 1.

86 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 1.

87 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 1. Potential candidates for Capability Concepts are referred to as Planning Concepts.

88 Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 1, 1.

Additionally, the UAS flight plan identifies some important roles that are intended to foster automation research towards foreseeable problems. The SecAF uses the document to specify that many of the anticipated RPA acquisition deliverables should come from the Aeronautical Systems Center.[89] The document tasks the Air Force Research Laboratory to provide Human System Integration subject matter experts for all UAS-related teams.[90] AFRL should help resolve human factors-related technology development, including those issues related to system design requirements.[91] Hence, AFRL/RH has a vested interest to clarify dialogue about autonomous technology developments for RPAs with diverse parties.[92]

Another external driver relies on an historical perspective about the important roles that manned aircraft formations have provided for the Air Force. During WWII, the Army Air Forces (USAAF) did not prefer to send single B-17s into battle to bomb Germany; rather, they flew large formations of bombers escorted by pursuit fighters to maximize lethality and to minimize defensive vulnerabilities during the attack.[93] Likewise, effective RPA formation capabilities could realize mission accomplishment well beyond the lone RPA strategies of today. One can envision a variety of roles for cooperative RPAs, such as fighters,[94] bombers,[95] aerial refuelers,[96] and transports.[97] Familiarity with the increasing sophistication of cooperative-control algorithms required for multi-RPAs motivates a diverse set of autonomy developments.

Strategic Opportunities: Drivers Internal to USAF RPA Acquisition Community

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[89] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 67.
[90] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 31.
[91] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 31.
[92] Mark Draper, *AFRL/RHCI Roadmap Meeting*, Wright Patterson AFB, OH, 18 February 2011.
[93] Richard G. Davis, *Carl A. Spaatz and the Air War in Europe*, (Washington, DC: Center for Air Force History, 1993), 556-58.
[94] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," *AIAA-2004-6125*, AIAA 1st Intelligent Systems Technical Conference, Chicago, Illinois, 20-22 September 2004, 1.
[95] Mark Thompson, "A New Bomber with No Pilot," *Time*, 7 April 2008. http://www.time.com.
[96] Air Vehicles Directorate (AFRL/RB), "AFRL Completes Automated Aerial Refueling Positions and Pathways Flight Tests," Air Force Research Laboratory, 15 January 2008, http://www.wpafb.af.mil.
[97] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 39.

Internal organizational moves today forecast an increased desire to exploit RPA-delivered effects. In shrinking Air Force budgetary projections, the SecDEF is advocating that the Air Force grow its RPA production.[98] The acquisition community cannot help but notice the continued support for the execution of the RPA career path, complete with Air Force Specialty Codes, training, and sourcing that began in 2010.[99] As a result, the USAF acquisition community wants to remain relevant for future RPA development. In the competitive environment for limited DoD research dollars, the RPA-related developments should attract sufficient resources for AFRL to support its customer base.

The strong desire to realize a user-defined capability serves as a second internal driver that would help the RPA acquisition community reorient its organizational structure. In order to characterize this, one can draw conceptual lessons derived from the MQ-X program experience. The MQ-X program expects to enable a replacement for the MQ-1 and MQ-9 RPAs, providing intelligence, surveillance, and reconnaissance, as well as kinetic effects. When considering the envisioned capabilities for the future platform, one can anticipate numerous automation technologies.[100] The *UAS Flight Plan* forecasts missions of a MQ-X acting alone, or acting cooperatively with similar platforms to achieve mission objectives.[101] Since the MQ-X development proposal was composed by informed representatives from ASC, AFRL, and other key entities, one can infer that the USAF can achieve the necessary automation technologies within the anticipated build schedule.[102]

Strategic Opportunities: More than Cooperation Needed to Acquire RPAs that Fly Jointly

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[98] Secretary of Defense Robert M. Gates, *Statement on Department Budget and Efficiencies*, U.S. Department of Defense Speech, www.defense.gov, 6 January 2011, 5.
[99] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 18.
[100] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 33-34.
[101] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 38.
[102] ACC/A8, *MQ-X Unmanned Aerial System (UAS) Functional Solutions Analysis (FSA) Report*, 3.

Architecture design becomes extremely challenging when mission requirements dictate that two or more different types of RPAs must work together, referred to as joint multi-RPA missions. For example, the MQ-1 Predator / MQ-9 Reaper SPO and the MQ-4 Global Hawk SPO have developed unique tasking processes. This distinction highlights the disparate design points articulated by theme 2 shown earlier in Figure 2 (p. 88). The MQ-1/MQ-9 ground control stations permit dynamic re-planning during a mission, while the MQ-4 requires preloaded mission commands.[103] Stealthy flight requires preprogrammed commands akin to how the MQ-4 flies today. [104] A future suppression of enemy air defense (SEAD) mission would require a similar programming approach.[105] Humans cannot improvise and fly the precise flight paths to sustain the concealment The system design requirements used to produce the ground control stations for these two RPA platforms are divergent. Cost prohibits current attempts to create a common ground control station of two or more disparate RPA platform-types.[106] If planned for in several future platform designs, the cost for automated joint multi-RPA mission decreases.

A thoughtful consideration of several figures explains why depending on a coordination strategy to maintain SDRs across platform-types intended for RPA networks breaks down, driving the need to alter the organization. Figures 4 (p. 90) and 5 (p. 91) focus on the production of a ground station that is interchangeable among RPA types. If one considers the Multiple Aircraft Control ground stations for the Predator/Reaper discussed in the previous Chapter, one could rely on its modular design to accommodate commonality for the near term RPA follow-on program currently referred to as MQ-X.[107] Figure 4 shows that such an arrangement could force a set of common SDRs among the ground segment components for the MQ-1/MQ-9 and MQ-X. A future MAC ground segment architecture could support a centralized cooperative-control approach, a subset

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[103] Major Brian Barker, *Predator/Reaper: Thoughts on MAC*, 5. Barker reveals the ability of MAC to accommodate quick-reaction replanning in response to pop-up threats. Also note Lt. Col. David Kacmarynski, Aeronautical Systems Center, Interview, 30 April 2011. Kacmarynski discussed about some of the difficulties experienced while Global Hawk (MQ-4) design teams attempted to introduce dynamic replanning capabilities.

[104] Mark Draper, Air Force Research Laboratory, Interview, 18 February 2011.

[105] Mark Draper, Air Force Research Laboratory, Interview, 18 February 2011.

[106] Major Brian Barker, *Predator/Reaper: Thoughts on MAC*, XX. [Retrieve page(s)]

[107] Major Brian Barker, *Predator/Reaper: Thoughts on MAC*, 9. Barker reveals the applicability for reusability with future RPAs. The MQ-X is the medium-sized RPA follow on to the MQ-1/MQ-9.

of the greater theory for RPA group autonomy. Figure 5 shows the natural extension of using ground station commonality as a way to impose common SDRs pertaining to cooperative control. The organizational approaches shown in Figures 4 and 5 impose the need for a coordinating group in order to ensure that the common ground station satisfies all interface SDRs pertaining to each contributing SPO.

To make RPA group-centric autonomous techniques more immune from issues like communication bandwidth denial, a more robust implementation of automated cooperative control requires that some pertinent computations are performed on the aerial platform. In other words, RPA group autonomy becomes more robust with decentralized cooperative control. This approach introduces the need for SDR coordination between all corresponding aerial vehicle and ground segment components, as shown in Figure 6 (p. 92). As automated tasking sophistication increases, this figure demonstrates how unruly the organizational structure might become if left to incremental adaptation and cooperation. Within the current acquisition community, the demonstrated reality is that the SPO dominates control of its SDRs.[108] The SPO coordinate SDRs between SPOs if and only if each can contain cost increases, schedule delays (a.k.a. schedule slips), or technical performance risk changes. Excessive SDR coordination external to the SPO highlights susceptibility to breakdown. How can the acquisition community posture itself to obviate the challenges associated with joint RPA group-centric autonomy?

Conclusion

This chapter provides many insights that relate how the Air Force Research Laboratory trail-blazes increasing levels of RPA autonomy. Engineers develop many technologies that enhance platform-centric autonomy during this period. They identify a number of challenges to group-centric autonomy as well. Unique working relationships between AFRL, AFSOC, and their supporting contractors promise to foster group-centric technology breakthroughs. This combination of actors will introduce the first two RPAs that work together semi-autonomously within the aerial battlespace of the IW campaign.

[108] "Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems," GAO Reports 09-520, 67.

After the technology group-centric RPA demonstration occurs in the operational environment, the challenges associated with sustainability, mission diversification, and RPA network operations will challenge the very nature of USAF acquisitions. The magnitude of challenges associated with building interoperable group autonomy overwhelms the informal advising connections, such as those that link ASC to AFRL. Stronger forms of coordination become even more important as policymakers reduce budgets over the past several years. AFSOC lacks the resources and organizational mission to sustain the effort to construct an RPA network. Although AFRL recently refocused its organization to better prioritize critical technologies such as those needed for group-centric autonomy, ASC retains its commitment to the SPO. Also, after delivering two RPAs that successfully demonstrate semi-autonomous cooperation, AFSOC dissolves its integrated product team to focus the personnel on new priorities. Will the USAF commit to autonomous RPA concept to reshape the aerial battlespace?

CHAPTER 3

2016-2050 – THE CROSSOVER: RPAS = WARFIGHTERS CONTROLLING THEM

Introduction

Evolutionary changes may permit dissimilar RPAs and manned aircraft to operate together in the far term, to pursue multiple objectives in the aerial battlespace. Referring to Figure 1 (p. 87), one can see that roughly forty years have elapsed from the timeframe described in Chapter 1. A challenging strategic environment lies ahead as China grows more assertive. Despite numerous technological breakthroughs, the delivery of autonomous technologies that enable RPA networks cannot arrive soon enough. Technologists demonstrate a robust form of decentralized cooperative control of RPAs. A standardized communication and implementation approach makes networked operations possible among disparate platforms. As technical barriers fall, normative resistance emerges. Although technically feasible, some missions remain *off limits* because of American norms to follow ethical and legal constraints to conform to the desired international order. In order to understand how the USAF reached this technological position, one must examine the strategic context that focused American efforts.

China's evolving threat focuses US strategic interests in 2050. Although growing at a slower rate than it did in 2011, China enjoys a relative growth advantage over the United States to achieve economic parity.[1] Table 1 (p. 94) reveals the economic projection using reasonably conservative assumptions. As illustrated through hegemonic cycle theory, US policy increasingly focuses on long-term objectives aligned with

[1] Central Intelligence Agency, *The World Factbook*, http://www.cia.gov/library/publications/the-world-factbook, October 2010. Economic projections in 2010 reveal that the US has a Gross Domestic Product (GDP) of $14.26 Trillion based on official exchange rates, with an estimated -2.6% real growth rate, reflecting the recession of the day. China's equivalent GDP is estimated at $4.909 Trillion, with an estimated growth rate of 9%. Also see Robert Gilpin, *War & Change in World Politics*, (Cambridge, UK: Cambridge University Press, 1981), 106-07. Gilpin recognizes that the hegemon suffers from both increasing cost of further expansion and diminishing returns in sustaining its international order. These costs are not required to tax the growth of a rising power.

national interests.[2] Near parity invokes reductionist logic, such that maintenance of the existing order becomes the interest that trumps all others.[3] Although hostilities have not commenced, a sense of uncertainty lingers with respect to the allegiances of states: some affirm their commitment to the status quo, while others rally to the competing league led by China. John Warden's framework from *Winning in Fast Time* motivates the anticipated strategic focus for RPAs and this international relations depiction serves as the overarching *Future Picture* to guide USAF objectives as it prepares for conventional war with a rising state challenger.[4] Relevant key descriptors from Warden drive Air Force decisions about organizing, training, and equipping for a mid-intensity conventional fight using RPAs in 2050.[5] The commander's intent benefits from the organizational and technical focus that has emerged, correlating to China's rise.

The next section captures the radical changes that occur to the acquisition organizations in the RPA community in order to meet the emerging threat from the rising power. Group-centric autonomy concepts blossom into a realizable RPA network. Following the dramatic budgetary reduction trends of the greater USAF, the RPA acquisition community budgets finally succumb to the pressures inflicted upon the DoD since 2012.[6] Organizations become more receptive to restructuring when pressed by extreme financial shortfalls.[7] The thesis considers the viable options and advocates for the most effective solution to achieve RPA autonomy in such an environment. Much of

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[2] Robert Gilpin, *War & Change in World Politics*, 6. The thesis uses Gilpin's hegemonic cycle theory again to frame and assess the new context.

[3] Stathis N. Kalyvas, *The Logic of Violence in Civil War*, (Cambridge, New York: Cambridge University Press, 2009), 208. Kalyvas characterizes the reductionist logic that occurs in a Civil War setting among local rivals of roughly equivalent parity. The characteristics extend to state vs. state struggle on the international stage in a bipolar world, as demonstrated by the US-USSR alignments from WWII to 1991.

[4] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 63-64.

[5] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.

[6] Robert M. Gates, *Statement on Department Budget and Efficiencies*, US Department of Defense, http://www.defense.gov, 6 January 2011, 1. The RPA community was largely protected in this round of DoD budget reductions. But, as US national debt exceeded its annual GDP, the military was reduced to alleviate some of the nation's financial pressures. The SecDEF could no longer protect the organizational transformation from manned aircraft to RPAs as the defense spending cuts intensified.

[7] Sir Arthur Tedder, *Air Power in War*, (Tuscaloosa, AL: The University of Alabama Press, 2010), 27. Tedder recognizes the need to create a national defense that is economically sound following WWII. When budgets are severely cut back, the organization must focus all resources towards its aim for the future. This paper is used to project that the budgetary position of the US in 2011 will force similar large scale refinements in military purpose in 2016.

the restructuring of the RPA acquisitions community helps foster technological advancement in key areas for group-centric RPA autonomy.

The third subsection will chart important technological considerations to realize autonomous advancements during the period. Decentralized cooperative control becomes the key to realizing a diverse set of RPAs for numerous missions in the aerial battlespace. With sufficient computational resources available on each platform, the acquisitions community can prioritize information sharing standards to foster the emerging RPA network. The solution balances the need for information transmission technologies, latency, bandwidth constraints, and robustness to sustain additions and losses in a hostile environment. Several other complementary technologies become important. Although these technologies help overcome operational limitations for group-centric applications, established international norms increasingly hold strategic opportunities in check, thereby restraining lethality.

The final section highlights emotional inhibitors to change. The technological expectations associated with automatic target recognition capabilities seem too tough to satisfy. Exhaustive procedures required to release the weapon still necessitate much of the human involvement still associated with RPA operation. The social norms reflect the continued use of RPAs in various IW environments spanning the decades leading to 2050. Can a state trust the release of an automated weapon that delivers lethal force? The numerous low-intensity conflict engagements affirm the need to maintain human involvement during lethal RPA operations. The political debate about such questions has only intensified as China's demeanor sours towards US-led international policy. How will the ailing hegemonic regime respond to that of a rising challenger?[8]

Strategic Focus

"[T]he process of international political change ultimately reflects the efforts of individuals or groups to transform institutions and systems in order to advance their

[8] Robert Gilpin, *War & Change in World Politics*, 39-40. Gilpin highlights three broad types of change that characterize a states relationship to the international system. A *systems change* is most far reaching, highlighting a change in the very nature of the actors themselves in how they operate as an international system. A *systemic change* is one that results in a different form of governance of the international system. Finally, an *interaction change* is confined to the regular interaction between states, as the international regime is left intact.

interests."[9] Emphasizing that the interests and relative powers of groups change with time, Robert Gilpin's framework offers valuable insights to a hegemon for potential policy revision. In 2050, the need to project power through non-nuclear means has become increasingly important compared to prestige in its ability to generate desired effects against an adversary.[10] Future international interactions rely more on demonstrated power through innovation, such as networked RPAs. Many states shirk from commitment to either side, as they wait to see whether China or the US emerges as the global leader. China's parity in economics, coupled with its increasingly capable conventional military forces, help to explain the posturing differences. Does the US sustain the international regime that it worked so hard to establish over the preceding century when challenged by the rising Chinese state?

The US relies on its military prowess as only one of its instruments of national power to shape an international order that reflects its interests.[11] Various episodes demonstrate the US ability to use its instruments of national power to thwart the efforts of challengers. Freedman, for example, discusses the economic and military policies that led to the collapse of the USSR when it rivaled the US through the 1990s.[12] One could make a case that by the late 1970s, Japan economically positioned itself to eclipse the US.[13] In this case, the US successfully reprioritized its economic interests to reverse the trend, thereby firmly reasserting itself as the global leader. With respect to the challenge posed by Al Qaeda from 2001 through the next decade, American led efforts to sever the

[9] Robert Gilpin, *War & Change in World Politics*, 10.
[10] Robert Gilpin, *War & Change in World Politics, 29-33.* This assertion flips the order of importance between power and prestige in terms of its ability to exert control over the international system in order to advance hegemonic self-interest. Gilpin's assertion was correct for his day, when nuclear deterrence focused the contest of wills between the US and USSR in a bipolar world. This essay is used to assert that nuclear deterrence is less important in a contest between the US and China in 2050.
[11] Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy*, (Princeton, NJ: Princeton University Press, 2005), xi, 30. Keohane focuses on the use of international regimes to promote a state's self-interest through mutually beneficial cooperation.
[12] Lawrence Freedman, *The Evolution of Nuclear Strategy*, 3rd ed., (New York: Palgrave Macmillan, 2003), 407-08.
[13] This topic was discussed in various SAASS seminars. Carnes Lord discusses the economic policy revolution that Ronald Reagan led to break the US malaise that manifest during the previous administration. See Carnes Lord, *The Modern Prince: What Leaders Need to Know Now*, (New Haven, CT: Yale University Press, 2003), 5-6.

connection between Islamism and individualized local contexts enabled the eventual dissipation of the remnants of the former international terrorist organization.[14]

In many respects, China represents a greater threat than any of these former foes. Combining its economic might, increasing military technological proficiency, and political hegemonic ambition, the rising power presses the leading state for concessions.[15] Further assessment relies on Gilpin's hegemonic cycle theory to analyze the lead up to potential major conventional conflict through 2050. The context provides the *Future Picture* for use of Warden's framework to set the strategic focus of RPA acquisitions.

Strategic Focus: A Guide to Frame Policy Revision

Learning to recognize Chinese intentions yields critical indicators for the correct timing of policy change. The social arrangements that hold the international order in place often favor the particular interests that reflect the relative power of the actors involved in the system.[16] In other words, selection by the leader fosters social arrangements that favor some over others, thereby facilitating advantage. As a result, China wants to craft a system that reflects its interests, as opposed to relying on one that privileges an aging regime. In order to understand what entities can best project their interests, one must characterize how control is perceived among states.[17] The ability to influence others gives actors power within the international order.[18]

The possibility of nuclear war occurring during a period of hegemonic decline inspired Gilpin to search for alternative actions. Previous hegemonic declines of record resulted in unlimited war to thwart rising challengers. Recall from Chapter 2 that Gilpin's work suggests three courses of action to address the challenge from a rising

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[14] Audrey Kurth Cronin, *How Terrorism Ends: Understanding the Decline and Demise of Terrorist Campaigns*, (Princeton, NJ: Princeton University Press, 2009), 167-68, 193.

[15] Robert Gilpin, *War & Change in World Politics, 207.* Gilpin's criteria of a credible challenge to the leading power are satisfied by China in 2050 in its endeavors against the US.

[16] Hedley Bull, *The Anarchical Society: A Study of Order in World Politics*, 3rd ed., (New York: Colombia University Press, 2002), 196, 200. Bull describes how great powers enjoy special rights within the international order that they dominate. They can exploit their preponderance relative to other states.

[17] Hedley Bull, *The Anarchical Society: A Study of Order in World Politics*, 221. Bull highlights that power states sustain the international order because other states support their efforts, both tacitly and directly.

[18] Kenneth N. Waltz, *Theory of International Politics*, (Long Grove, IL: Waveland Press, 2010), 185. Waltz recognizes that because power maintains international order, powerful states need to use force less than weaker neighbors because the strong can threaten to protect their interest.

power and to avert unlimited war in a nuclear world. One option recommends that a declining hegemon pursue a negotiated reordering.[19] A second option has the declining hegemon pursue a series of limited wars against the rising powers.[20] A third option suggests that the hegemon disengage from some international obligations in order to retain the ability to defend others.[21]

Robert Keohane built upon Gilpin's first reordering option when he proposed that the United States should embrace liberal institutionalist structures.[22] The international institutions successfully propagate a form of US values. Additionally, when faced with the consequences of hegemonic decline, then President Ronald Reagan chose to retrench spending priorities, thereby enabling the US to reassert leadership. This successful application of Gilpin's third approach invigorated America's global leadership, particularly in the economic, military, and information domains. The context pertinent to China in 2050 differs from previous challenges, given continued US economic erosion. China presents a challenge to leadership in several dimensions: economic, military, and diplomatic. Numerous states wait to see which power will emerge victorious.

If the US declines and faces an increasingly belligerent China, preparing for a modern conventional conflict that mimics the scale of the Korean War in the 1950s would prove useful. A strategy that prepares to embrace Gilpin's second reordering approach is needed to provide a viable option to thwart such a challenge. Disengagement from some areas will likely remain necessary in order to afford the cost of preparing for war using new technologies for asymmetric advantage. During a time of reductionist focus against China, the US would prioritize those programs that best prepare it for war.

Strategic Focus: Warden's Guide for the RPA Context in 2050

With the Chinese threat articulated, the USAF will try to shift its efforts to project power with RPAs. Thus, the *Future Picture* demonstrates the opportunity for a strong reliance on automated collaborative RPAs within the aerial environment. The US

[19] Robert Gilpin, *War & Change in World Politics*, 208.
[20] Robert Gilpin, *War & Change in World Politics*, 216.
[21] Robert Gilpin, *War & Change in World Politics*, 192.
[22] Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy*, 9.

fascination with technology has turned the architecture into its most pervasive weapon.[23] The concentrated effort to reduce the man-to-RPA ratio represents the cumulative average across diverse platforms.[24] Much of the realization of group autonomy corresponds to single-purpose sensing missions, in which the RPAs are not retrievable.[25] However, some applications, such as RPA formation flying for close air support (CAS) missions still have large manpower needs. The social norms associated with RPA lethality reflect the patterns established for IW or peacetime.[26] Despite the growing concerns about China in a conventional war, politicians and their appointees continue to favor RPA employment policy that requires numerous human authorizations for verification and validation.[27] This policy risks effectiveness and efficiency in conventional war.

With the *Future Picture* characterized, Warden advises organizations to consider what expectations they have for the organization within the anticipated operating environment.[28] More specifically, Warden advocates a sufficient breakdown of the *Future Picture* in order to add detail to the expectations.[29] The acquisitions of diverse joint-RPA constellations demonstrate truly novel procurements. In order to push the state-of-the-art in a controllable manner, the organization that produces the RPAs will manage technical complexity with a spiral acquisition strategy that attempts to balance

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[23] Carl H. Builder, *The Icarus Syndrome*, (New Brunswick: NJ, Transaction Publishers, 2003), 155.
[24] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011.
[25] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011. For example, a single mission platform could be tasked to search for and detect for nuclear emissions. When achieving its objective, these platforms can relay a message to command. For simplicity, expendable launch vehicle operations could make this objective realizable in the 2050 timeframe. The ability to avoid a collision and to partake in decentralized collaborative control with different platform types in order to efficiently relay information becomes the primary technology challenge.
[26] Michael Walzer, *Just and Unjust Wars: A Moral Argument with Historical Illustrations*, 4th ed., (New York: Basic Books, 1977), 44. Walzer described a war convention as a set of articulated norms, customs, codes, principles, and reciprocal arrangements that shape judgments about military conduct. His book helps to explain how norms developed in one mode of warfare could constrain application in another type of war.
[27] Robert Jervis, *Perception and Misperception in International Politics*, (Princeton, NJ: Princeton University Press, 1976), 117, 140. Jervis description of cognitive consistency relates how people see what they expect to see, based on pre-existing ways of operating. Such an approach becomes irrational when one chooses to operate in a manner that is consistent with pre-existing expectations, but is inappropriate for the new context. One can fail to reach critical operational goals if hampered by numerous expectations, especially those constraints that are inappropriate.
[28] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63-64.
[29] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 65.

risk with successful implementation.[30] With some amount of innovation introduced in appropriate block procurements, other technology aspects purposely mimic the previous iteration. Platform artifacts from one block iteration may not remain compatible with RPAs in a subsequent block. Therefore, all iterations need to carefully evaluate what compatibilities are needed to sustain successful group operations in a dynamic aerial battlespace. This spiral acquisition approach encourages continuous, controlled expenditure of non-recurring engineering (NRE) towards the desired subsequent block. Program managers define NRE as a one-time cost of R&D needed for a new product.[31] Systems engineering will perform the critical role in balancing innovation risk, block completion, and RPA network realization.

In order to supply a level of specificity about how block procurement advances, the USAF acquisition community should consider procuring RPAs in the following iterations. First, Block 1 is comprised of two RPA types, with at least two platforms of each vehicle-type. The effort should incorporate centralized cooperative control algorithms, thereby controlling all RPAs from a single ground location. Block 1 demonstrates algorithm sufficiency from the ground station. As a secondary objective, RPAs originating as part of Block 1 become equipped with sufficient computational abilities to perform cooperative control algorithms from within each RPA. This configuration will demonstrate a proof of concept and incorporate the capacity for future upgrades as technology progress to decentralized execution.

Next, the organization could build Block 2, again comprised of four RPAs, two of each different vehicle type. Block 2 demonstrates decentralized cooperative control algorithms. Redundancy at the ground station provides a validated back-up scheme. Once successful, software engineers test algorithms for increasingly complex flying arrangements, thereby expanding the flight envelope for RPA group autonomy.

The final method of demonstration of this example of spiral acquisition is accomplished with Block 3, in which six RPAs are procured, representing three sets of different vehicle types. The block demonstrates the flexibility of the decentralized

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[30] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02*, 8 December 2008, 12, 13. Spiral acquisitions are also known as evolutionary acquisitions, which delivers successive technology improvements in increments.
[31] Defense Air University, "Cost Estimating," *PMT250*, 11 May 2011, 7.

cooperative control algorithms that comprise a variety of working combinations. Operators demonstrate complex cooperative formation flying missions. Successful RPA network demonstrations propel certain technologies to emerge as standards. These critical enabling technologies thereby transfer to developing program offices because the interested parties want the new platforms interoperable with the emerging RPA network. Block 3 serves as the nucleus from which to foster cooperative channels to other program offices, other DoD services and agencies, and even international partners. Such an approach provides yet another example of positive conquest, as others adopt the standards established by those programs that succeed to demonstrate networked RPA operations.[32]

At this point, Warden recommends that an organization characterize relevant key descriptors to detail the grand strategy for the acquisition of RPA automation for conventional warfare.[33] As in all novel engineering endeavors, innovation becomes an important descriptor.[34] Because the USAF wants to build a network that hosts different compositions of RPA platforms, ACC and ASC represent the best host organization and customer for such an endeavor. The next section proposes a new type of organization that fosters the second important descriptor of ownership.[35] The acquisition strategy needs to focus for a long time horizon. Yet, it needs to embrace the ability to ensure design flexibility for new platform iterations. A special integrated product team would represent the optimal acquisition strategy. The organization's desire to ensure interoperability for its customers ultimately becomes an important mechanism to foster RPA networks.

Relevant Organizational Aspects

The USAF should acquire increasingly automated RPAs equipped to work collaboratively in the dynamic aerial battlespace in 2050. The previous organizational system for acquisitions hindered the evolution of group-centric concepts. The old

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[32] Martin C. Libicki, *Conquest in Cyberspace: National Security and Information Warfare*, (Cambridge, UK: Cambridge University Press, 2007), 3, 126, 182.
[33] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.
[34] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 67.
[35] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 67.

organization shortcomings ranged from a failure to realize significant system performance capabilities to–worse yet–the failure of a platform to integrate into the RPA network. The new organization forged an entity that obligates platform developers to craft each vehicle to function in a network of diverse platform types. The new organization simultaneously maintains sufficient authority to ensure design flexibility that satisfies platform system design requirements.

The acquisition community has traditionally leveraged the use of the SPO as an organizational construct to address the social, economic, political, and technical factors for RPA design despite competing demands.[36] One can depict the severity of competing demands and operating environment as a hostile environment that complicates the development and construction of the system.[37] When taken to the extreme, competing demands can disassociate a project from completion.[38] To counter this hostile environment, several organizational approaches are now considered for their effectiveness in building an expanding RPA cooperative network. Organizational cornerstones, such as RPA SPOs within ASC, should only attempt modification with great care to transform it gradually and as justified.[39]

Potential Organizational Alternatives

A possible way to create an RPA network entails building multiple platforms simultaneously within a SPO. This suggestion mirrors the recommendation proposed for AFSOC in Chapter 2. In the former case, AFSOC utilized a lean, integrated product team to solve the problems envisioned for warfighters in their present endeavors. This approach speeds innovations to the customer. A SPO could add procedural rigor and provide organizational backing to ensure the product lasts for a lengthy operational life.[40]

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[36] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," In *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: The MIT Press, 1987), 112.
[37] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," 116-17.
[38] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," 114.
[39] Michael Callon, "Society in the Making," in *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: Massachusetts Institute of Technology Press, 1987), 89.
[40] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 77.* Longevity represents a design variable, developed in accordance to the system design requirements for the RPA

This organization approach protects much of the working culture that the acquisitions community knows.[41] The biggest challenge derived from such an approach pertains to the expandability of application platform sets. Interoperability with platforms produced by external organizations is not guaranteed.

The second organizational approach follows the template of establishing a controlling board at the DoD level with a charter of ensuring interoperability of RPAs.[42] This approach also has an advantage of representing a form of organization familiar to the USAF.[43] For instance, the SecDEF recently established a working group to help generate dialogue and department-level guidance for autonomy.[44] This approach promotes effectiveness; however, the guidance from such an organization can lack insights into the technical trade space of the specific program. This group does not really set system design requirements for a program. Although a control board could levy a standard, a SPO can waive provisions, depending on the needs of the program. This begs the question of how group-centric network architecture remains intact to ensure the artifacts are interoperable with platforms produced by other SPOs, DoD services, agencies, or states. System design requirements become the mechanisms that hold the design of a product together. The acquisitions community, therefore, needs an alternative structure to ensure realization of group-centric SDRs for networked operations.

Revising the Organizational Structure: an RPA Architecture Office

A new architecture office becomes the organizational centerpiece to work through the technology challenges to realize RPA group-centric autonomy in 2050.[45] As Figure 7

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platform. The acquisitions community plans for such requirements through the acquisition life cycle for each artifact.

[41] Defense Air University, "Program Office Organizational Structures," *PMT352B*, Version 1.2, 13 September 2009, 2-3. An Integrated Product Team (IPT) integrates all the necessary process to provide the product for the customer, in accordance to the system design requirements. The IPT is the underlying basis in which to organize the SPO.

[42] Mark Draper, Air Force Research Laboratory, Interview, 18 February 2011.

[43] Mark Draper, Air Force Research Laboratory, Interview, 23 August 2010. The DoD working groups are typically organized around some technological theme, such as autonomy formed in 2010.

[44] Mark Draper, Air Force Research Laboratory, Interview, 23 August 2010. Also see Mark Draper, *AFRL/RHCI Roadmap Meeting*, Wright Patterson AFB, OH, 18 February 2011. The DoD level working group for autonomy is one of the overarching guides used to generate the branch level roadmap.

[45] This organizational structure was originally proposed as part of an Air Command Staff College thesis written by the author. In that case, the structure was devised to better synchronize RPA production

(p. 93) reveals, this office would retain control of all aspects that are essential for multiple vehicle coordination, while reserving authority for all other acquisition functions for RPA design with organizations akin to today's traditional RPA SPOs. For clarity, the author will refer to this re-characterized entity as a RPA program element to differentiate it from today's SPO. This new organizational structure will also enable scalability. It also ensures design flexibility at each level of integration. Likewise, it avoids the threat of paralysis that might occur if all system design requirement decisions are made exclusively by a small group within an overly centralized system program office.[46] An overly centralized architecture office would suffer from a lack of responsiveness to differentiate and tailor RPA platforms. Additionally, a central office that has exceeded its span of control would suffer from the perception of having little design credibility, setting up a counterproductive work environment, as employees from the design SPOs could protest against the perceived overreach.[47]

The architecture program office becomes responsible for the critical design requirements that maintain RPA network functionality. Defining system design requirements needed to achieve group-centric autonomy represents the most important role of the architecture office. SDRs for the architecture would need to ensure sufficient resource capabilities onboard each platform in order to realize the objectives consistent with the multi-RPA missions. This approach would require a significant investment in a staff with exceptional coordination, configuration management (CM), risk management, and multi-disciplinary engineering skills.[48] The architecture office must emphasize responsive interaction with and between SPO elements. The architecture office

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activities to produce joint RPA formations. The organizational concept extends nicely to the more generalized case considered here, one that promotes technology for group-centric autonomous flight.

[46] Mark R. Peattie, *Sunburst: The Rise of Japanese Naval Air Power, 1909-1941*, (Annapolis, MD: Naval Institute Press, 2007), 99-100. When considering an historic example of an aircraft industry that concentrated its technical experts at the top of their industrial scale, Peattie highlights this as one of several deficiencies that prohibited Japan to update its aviation related forces compared to its WWII competition, the United States. Peattie criticizes the bottlenecks that were created by the over concentration of design authority into centralized design entities that were unable to manage such authority. This examples serves as a fair warning against an over concentration of power within the architecture office described here, to the detriment of the SPO elements.

[47] Stathis N. Kalyvas, *The Logic of Violence in Civil War*, 336. Kalyvas characterizes the vulnerability that parties have to other local groups, based on the intimacy they share. Although originally developed in a Civil War setting, the logic extends to the make-up of an organization if an environment emerges that does not stifle local rivalries.

[48] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 77, 78.*

provisions change and synchronizes the developments of the SPO elements. Finally, ASC can add or remove RPA program elements to accommodate service needs with time. Given ASC's history in fostering sustainable program management organizations to produce sustainable artifacts over the long term, this organization represents the best parent organization in which to prepare for sustained group-centric autonomy. The UAS flight plan, moreover, recognizes ASC's capacity to oversee SPO's that have created complex systems in the past.[49]

To produce and sustain an RPA network in which the composition of platforms evolves with time and innovation, the architecture office must guide unique, self-sustaining RPA SPO elements. First, the architecture management office oversees the development of a testing approach to ensure that the RPA platforms demonstrate compliance with the greater RPA network.[50] Second, the architecture office should tie payments for the SPO elements to successful integration compliance objectives through successful test program demonstrations.[51] They complete these events according to predetermined milestone reviews and decision points. Finally, the architecture office should tailor the test program to utilize a virtual model (VM) to demonstrate intermediate aspects of group-centric autonomy because of high software dependency. This concept sustains design flexibility options while helping the architecture office adjust testing schedules while working to accommodate production schedules from diverse SPO elements.[52] Together, these tools serve the architecture office as it expands the RPA network.

Centrally Coordinated Systems Engineering Function

To counter this hostile environment as it attempts to work against the organization proposed in Figure 7 (p. 93), a centrally-coordinated systems engineering (SE) function

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[49] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, Washington DC: Headquarters, United States Air Force, 18 May 2009, 67.
[50] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 50.*
[51] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 12, 77.*
[52] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 12, 71. SPO element Program Managers will retain the appropriate authority to manage cost, schedule, and budgetary considerations with respect to the production of the artifact to satisfy their design requirements. Because the proposed organizational arrangement proposed here advocates that the architecture office control the SDRs associated with the RPA network, the capacity and flexibility to assure compliance of group autonomy must be maintained here as well.*

will help the program managers to integrate many specialized parts into a complex whole.[53] SE will help the architecture office manage all SDRs related to the RPA network and ensure that they interface with SDRs maintained by each RPA program element. This SE function "can see interconnections" over projects and can "communicate a central vision to the specialized engineers."[54] Given the complexity of both the problem and solution domains, all appropriate SPO elements include SE representation. In other words, systems engineering should create an integrated development environment (IDE) that enforces responsibilities at each organizational level and coordinates a consistent message.[55] Important dialogue through SE channels helps the architecture office achieve RPA group-centric autonomy objectives, while preserving the design options that still satisfy the platform system design requirements.

A successful, centrally-coordinated systems engineering function ensures that all platforms that will interact with the RPA network maintain an ability to satisfy mission requirements, despite environmental uncertainty.[56] Group-centric activity for RPAs requires adequate robustness. In this case, robustness describes the ability of the RPAs to overcome uncertainty while accomplishing a mission.[57] One would suspect that communications bandwidth (BW) and on-board RPA computational capability are important variables for uncertainty considerations. The systems engineers must have a general understanding of how cost relates to decisions that impact multiple vehicle-types. In particular, the overarching program office must retain the ability to address unknowns that can adversely impact design costs among numerous SPO designers. In order to accomplish this function effectively, the systems engineering function within the overarching program office retains control of certain performance capacity reserves on

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[53] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, (New York: Vintage, 2000), 122.
[54] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, 122.
[55] John J. Young, Jr., "Operation of the Defense Acquisition System," *DoDI 5000.02, 12, 77. The Systems Engineering Plan (SEP) will serve as a primary coordinating document between SE embedded within the architecture office and within each participated SPO element.*
[56] David J. Lonsdale, *The Nature of War in the Information Age: Clausewitzian Future*, (London: Frank Cass, 2005), 54. The RPA network is an extension of the network-centric future battlespace that Lonsdale describes. Equally applicable are the concepts of uncertainty that are described for the domain.
[57] Tal Shima, Steven J. Rasmussen, and Phillip Chandler, "UAV Team Decision and Control Using Efficient Collaborative Estimation," *Journal of Dynamic Systems,* Measurement and Control 129, no. 5 (September 2007): 610.

each RPA. For example, a multi-RPA system may need the addition of a learning module to improve RPA flight path determination for greater performance.[58]

In addition to helping the overarching program office manage some of its authorities, the centralized coordinated systems engineering would take the lead on managing technology risks. SE would oversee and inform the SPO element design engineers about the impact of important tradeoffs, such as decentralized or centralized-control approach,[59] the amount of predictive capabilities about formation members,[60] the magnitude of global or local information,[61] or scalability of members for cooperation.[62] It would need to develop reference models for all aspects of the elements it desires to control in joint missions. The SE function also has to execute multi-segment testing, chair engineering reviews, develop Request for Proposal (RFP) level specifications, and assess whether proposed solutions met the criteria of the architecture office.

RPA User Community Relationships

With respect to a proposed RPA network, AFSOC needs to become increasingly connected to ASC as platform elements of the constellation emerge. Air Force Special Operations Command possesses flexibility of response. AFSOC benefits from the ability to manipulate its platforms into the USAF RPA network at times, and then disengage as a threat dictates. In other words, rather than risk isolation in the aerial battlespace of 2050, AFSOC should seek compatibility. AFSOC IPTs should coordinate with the architecture office based in ASC to adopt the system design requirements that promote RPA network interoperability.[63] Even though AFSOC and ASC do not rival each other directly, they compete to attract the efforts of research talent, to include engineers at AFRL. Also, all Air Force sub-organizations should standardize their approach towards group RPA

[58] Jodi Miller et al., "Intelligent Unmanned Air Vehicle Flight Systems," *Journal of Aerospace Computing, Information and Communication*, 4 May 2007, 828.
[59] Tyler H. Summers, Maruthi R. Akella, and Mark J. Mears, "Coordinated Standoff Tracking of Moving Targets: Control Laws and Information Architectures," 56.
[60] Tal Shima, Steven J. Rasmussen, and Phillip Chandler, "UAV Team Decision and Control Using Efficient Collaborative Estimation," 610.
[61] Tal Shima, Steven J. Rasmussen, and Phillip Chandler, "UAV Team Decision and Control Using Efficient Collaborative Estimation," 610.
[62] Tyler H. Summers, Maruthi R. Akella, and Mark J. Mears, "Coordinated Standoff Tracking of Moving Targets: Control Laws and Information Architectures," 56.
[63] Martin C. Libicki, *Conquest in Cyberspace: National Security and Information Warfare*, 126. The mechanism of positive conquest can be extended to USAF sub organizations, as demonstrated here.

autonomy. As an additional benefit, this proposal acts as a mechanism to divide labor among USAF sub-organizations, thereby sustaining AFSOC's role as a trailblazer for R&D initiatives.

How does AFRL Interface with the New Production Entity?

The new organizational construct for procurement facilitates dramatic improvement in the ability to tap the creativity from AFRL to resolve strategically important technical problems related to autonomy. First, the production organization now looks a lot more like AFRL. The organizational changes occurring within AFRL in the summer of 2010 positioned the organization to work rapidly for strategic customer challenges.[64] As a *Flagship* program, the laboratory prioritizes its attention to specifically address customer needs and has funding already in place to assure transition.[65] These programs also garner the attention of the AFRL commander and the laboratory's organizational SE for requirements and evaluation criteria.[66] This approach reinforces the concept of the *technology spotlight* discussed earlier as a method to recognize that certain individual technologies can grow exponentially at times.[67] For *Flagship* programs, AFRL focused vast resources and attention to strategic problems. Once ASC has embraced the organizational construct of the RPA architecture office, requirements become more streamlined to identify. Plus, the magnitude of the implications impacting several platform-centric SPOs only adds to the sense of urgency when ASC uses the technology spotlight to identify its problem in the RPA network.

The other important similarity that has emerged with the ASC organization realignment pertains to the centralized SE. Now, both the RPA architecture office within ASC and AFRL has centralized SE to streamline interests of super organizations.[68]

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[64] Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, AFRL Memorandum, Wright Patterson AFB, OH, July 2010.
[65] Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 2.
[66] Major General Ellen Pawlikowski, *Guidance Memorandum for AFRL Integrated Planning and Programming (IPP) Process*, Attachment 3, 2.
[67] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, (San Francisco: Berrett-Koehler Publishers, 2006), 119.
[68] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, 122. The creation of centralized SE functions within AFRL (in the summer of 2010) and as proposed here for ASC expand the applicability of the coordinating ability, now across USAF organizations.

Communication opportunities help both AFRL and ASC posture for technical challenges preemptively, rather than reactively.[69] A successful, centrally-coordinated systems engineering function in both AFRL and ASC's RPA architecture office increases transparency to support interoperability within the RPA network.[70] Finally, ASC becomes more empowered to seek AFRL as a partner for technology transition for RPA autonomy.

Technology Trend Observations

With the significant organizational paradigm shift occurring in the USAF acquisitions community, the ingenuity pertaining to RPA group autonomy is unleashed. AFRL can act as a central actor through the RPA architecture SPO to facilitate network based autonomy innovations needed for design and production. Although incomplete, this section captures enough information to draw meaningful observations concerning developments that are important to the timeline proposed within the SecAF visionary flight plan.[71]

Importance of Decentralization of Cooperative Control

The importance of implementing decentralized cooperative-control algorithms for a system of RPAs depends on the importance of the mission against the cost of the platforms. In order to better understand design implementation options available to engineers, consider the brief explanations of three categories of approach. First, hierarchical-class approaches require that each RPA within the architecture has a high degree of global information.[72] They produce very high team performance, but require excellent network connectivity and communication throughput. Second, behavioral-class

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[69] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*, 122.

[70] David J. Lonsdale, *The Nature of War in the Information Age: Clausewitzian Future*, 78. Lonsdale describes some approaches that might become useful in reducing friction in preparing to exploit the future network-centric battlespace. The example offered here represents a proposed norm for interaction within the new RPA organization, also intended to reduce friction resulting from interaction.

[71] Secretary of the Air Force Michael B. Donley, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, 34.

[72] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," *AIAA-2004-6125*, AIAA 1st Intelligent Systems Technical Conference, Chicago, Illinois, 20-22 September 2004, 20, 22.

approaches exclude global information.[73] RPAs only interact by exchanging data with neighboring RPAs. With simple rules and minimal bandwidth requirements, this approach provides the least team cohesion. Finally, within the cooperative-class approaches, RPAs share a minimal level of global information within the package.[74] It balances the need for team cohesion, and greatly reduces the amount of communication bandwidth required. The cooperative-class approach balances performance outcomes with the need to compensate for operational realities of information transmission latency and architecture robustness.[75] Multi-RPA missions should strive to incorporate this latter organizing theory.

Technology Trends for Communications

The USAF must devote attention to the communications required to automate cooperative control for its RPA fleet. The proposed organization becomes pivotal to ensuring SDRs depict BW and frequency flexibility to achieve joint multi-RPA missions. Applications need sufficient BW for communication in order to implement the cooperative control strategy. Understanding the evolving communications environment becomes an important activity that a centrally coordinated systems engineering would carefully master. In a recent demonstration of technology, an aforementioned MAC ground station stayed well within the communication bandwidth available to command two Predators.[76] Communication time delays can hurt cooperative-control performance, as revealed in a case in which way-points were not uploaded fast enough to prevent significant overshoot distances while uploading new plans.[77] Also, ground control stations must demonstrate proficiency in handling lost-link contingencies in which multiple RPAs are involved.[78]

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[73] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," 20, 22.
[74] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," 20, 22.
[75] Phillip R. Chandler, "Cooperative Control of a Team of UAVs for Tactical Missions," 20, 22.
[76] Major Brian Barker, *Predator/Reaper: Thoughts on MAC*, Predator/Reaper Control Segment, Wright Patterson AFB, OH, 12 February 2010, 5.
[77] Steve Rasmussen, Michael Holland, and Adam Bry, "COUNTER Cooperative Control Algorithms: Challenges and Lessons Learned," *AIAA-2008-6313,* AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008, 10.
[78] Lt. Col. Jeffery W. Eggers and Mark H. Draper, "Multi-UAV Control for Tactical Reconnaissance and Close Air Support Missions: Operator Perspectives and Design Challenges," Human Factors and Medicine Panel of the NATO Research and Technology Organization, 2006, 6. Eggers reveals the practical

If technical assistance is needed to address a severe shortage, program design engineers could pursue a technology remedy. For instance, R&D could develop appropriate estimation parameters to mathematically model and predict the delay duration, so that that the cooperative control algorithms can attempt to subtract its predicted effect.[79] This approach enables design engineers to minimize the degradation of mission effectiveness for a cooperatively controlled set of RPAs.

Adopting STANAG 4586 Compliance

The Air Force's inability to converge upon a standardized data link interface and software architecture methodology for controlling the RPA network has plagued group-centric autonomous developments in the ground control stations. In 2010, the USAF tried to impose the High Level Architecture upon its organizational constituents.[80] Unfortunately, this analysis anticipates that the USAF acquisitions community does not embrace the software construct, based on the desire to maintain platform design flexibility for as long as possible.[81] Desperate for a solution, the USAF turned to the Army's convention of embracing STANG 4568 as a standard for the data link interface, which had diligently imposed a common operating standard among its ground control stations.[82] This approach effectively standardizes message implementations, code generation, and analyzer, which implements in one of the conventional languages of choice – C, C++, or JAVA. [83] With the focus increasingly towards RPA group-centric autonomy, the USAF adopted the standard as the only viable option mature enough for RPA networks. For years prior, the USAF had only pushed for module standardization to retain flexibility in the software architecture.[84] Adopting STANG 4568 as the software standard represents a balance between providing a trade space to foster sufficient

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considerations that occur during RPA operations, including the loss of communication links with the vehicle. Such a scenario is potentially more uncertain when multiple vehicles are involved.

[79] Meir Pachter, Nicola Ceccarelli, and Phillip Chandler, "Estimating MAV's Heading and the Wind Speed and Direction Using GPS, Inertial and Air Speed Measurements," *AIAA-2008-6311*, AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, 18-21 August 2008, 1.

[80] Modeling and Simulation Coordination Office, *High Level Architecture*, www.msco.mil.

[81] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.

[82] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011. When asked what the USAF solution might become if the importance of group-centric RPA applications rises, Feitshans did not know of any reasonable competitors today compared to STANG 4586.

[83] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.

[84] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011.

creativity and with enough standardization to ensure network RPA interoperability. Plus, the international community already embraces the Army's software compatibility standard.[85]

Strategic Opportunities

"People who favor a policy usually believe that it is supported by many logically independent reasons …"[86] Robert Jervis reveals the perverse nature of irrational consistency that might not fit the strategic necessity of the day. Despite many novel technological breakthroughs and a pervasive organizational recharacterization among acquisitions and operators, social norms inhibit the USAF from using RPAs to their full extent. The rising state challenger will try to exploit American norms to exercise extreme caution and care while using these stand-off weapons of asymmetric advantage. On the apparent eve of war, automated target recognition (ATR) technology remains insufficient to satisfy many Law of Armed Conflict adherents.[87] Some advocates are outright hostile to perceived American intentions with mechanized advantage.[88] In a polarized debate, when fact often becomes embellished with hype, policymakers must sort through the fog and craft policy. The next chapter considers US policy that will foster military power through networked RPA as the best position the state and its allies can take to prepare for and win future wars. Even though the aforementioned hegemonic cycle theory suggests that the threat posed by a belligerent China to the international order is sufficient, will the US continue to limit lethality options available through its RPA fleet?

Conclusion

[85] Greg Feitshans, Air Force Research Laboratory, Interview, 17 February 2011. STANG 4586 was standardized through NATO. Also see Martin C. Libicki, *Conquest in Cyberspace: National Security and Information Warfare*, 3, 126, 182. The USAF adoption would complete the US Army's successful effort to achieve positive conquest over rival conventions. This reinforces the applicability to non-state actors, even two that fight together in joint campaigns.

[86] Robert Jervis, *Perception and Misperception in International Politics*, 128.

[87] Meir Pachter, Air Force Institute of Technology, Interview, 12 February 2010. ATR is hard to accomplish by today's expectations. Some have suggested that it will likely become the lagging requirement for RPA autonomy.

[88] Dennis Delestrac, *Pax Americana*, (Carnegie of Canada, 2009). Although the arguments made in this documentary were geared towards space weapons, many points against space weaponization would transcend to any mechanized stand-off weapon in which the US enjoys clear asymmetric advantage.

This chapter provided many insights about how the USAF acquisition community may choose to respond to an increasingly serious strategic threat. In response to the perceived challenge from China as the rising state, the hegemon may become quite motivated to change its approach.[89] The ability to leverage RPA group autonomy advantages may yield asymmetric advantage in a conventional conflict modeled on the Korean War. This *Future Picture* motivates an acquisition strategy reliant on successive block procurements to realize group autonomy by the eve of war. The acquisition community needed a dramatic organizational reconfiguration to acquire RPA networks that seamlessly accommodate future platforms. ASC remains the sustaining hub to the architecture innovation and interoperability. Numerous technological advances have occurred to make this stand-off weapon available; however, the automated target recognition advances have proven too difficult to achieve. On the eve of a colossal challenge, the US must decide how to overcome its deficiencies in this critical technological area.

[89] Robert Gilpin, *War & Change in World Politics*, 207.

CHAPTER 4

2050-2060 – UNMANNED NETWORK WARFARE IN THE AERIAL BATTLESPACE

Introduction

The evolution of the RPA network will permit dissimilar RPAs and manned vehicles to operate together to pursue multiple objectives in the heterogeneous aerial battlespace. Referring to Figure 1 (p. 87), one can see that roughly fifty years have elapsed from the case study datum described in Chapter 1. The figure shows that the minimum number of humans used to operate the RPA fleet reaches a practical limit. The operators employ some number and mix of RPA platforms to achieve a mix of capabilities anticipated to levy the desired effects. Many capabilities permit a platform-to-human operator greatly exceeding 1-to-1. However, this rule-of-thumb does not always apply, particularly for the most lethal missions that involve the most complex RPAs.

The preceding *Strategic Opportunities* section described the previous normative dilemma experienced by the USAF. A major conventional battle occurs between the hegemon of the old international order, the US, and the coalition led by the rising power, China. During conflict, the warfighter often revises formerly prescriptive norms that impact they ways of war, including those associated with RPA operations.[1] Although still short of the pre-war standard, advances in automated target recognition are considered good enough to exploit the collaborative RPA network lethality. Standardized implementation of key aspects permit networked operations among disparate platforms.

In order to motivate the discussion, one must anticipate the strategic interests of the US in 2060. The *Strategic Focus* section emphasizes what occurs after the US defeats the threat posed by China as the rising power. Reflecting on Robert Gilpin's hegemonic cycle theory, US policy increasingly focuses on economic growth after the

[1] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011.

decisive military victory in 2057.[2] As such, the US retrenches from some of its global military commitments in order to recover from the costs of war.[3] For USAF organizational leadership, the emphasis becomes an effort to preserve the ability to reconstitute the asymmetric advantage while downsizing, akin to that which motivated the downsizing efforts following WWII. Guidance from Stephen Rosen fits well as it encourages a force to emphasize the perceived threat while sustaining exploratory R&D to permit rapid reconstitution if needed.[4]

John Warden's framework from *Winning in Fast Time* motivates the focus for development of RPA acquisitions strategy. The international relations characterization will serve as the overarching *Future Picture* to inform how the acquisitions community will react to the turbulence created in dramatic downsizing.[5] Relevant key descriptors from Warden's recommended list will then motivate how the USAF will retain its ability to reconstitute, despite not knowing much about the nature of the future threat.[6]

The next section briefly considers the radical changes that occurred to the acquisition organizations in the RPA community in response to the emerging threat from the rising power. The world embraces new norms because of the overwhelming successful demonstration of aerial superiority by America's use of cooperative RPAs.[7] Hence, the acquisitions community embraces a firm commitment to retain the RPA group-centric autonomy core capabilities. The RPA architecture office is retained. The platform-centric SPOs are arranged to permit expansion and contraction as platforms are envisioned for the future RPA network. Individual SPOs are thereby prioritized for preservation based on anticipated future threats. The USAF decides to sustain the working relationship between the architecture office and the platform-centric SPOs. Finally, the analysis provides some details about automated target recognition technology

[2] Robert Gilpin, *War & Change in World Politics*, (Cambridge, UK: Cambridge University Press, 1981), 230.
[3] Robert Gilpin, *War & Change in World Politics*, 192.
[4] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, (Ithaca, NY: Cornell University Press, 1991), 243-44.
[5] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 63-64.
[6] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 66-67.
[7] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 75. Rosen highlights that the behavior of an organization can change, particularly if the innovations are connected to preparation and demonstrated in war. Actualization occurs to embrace the processes that facilitated the innovation in such cases at the 2057 scenario proposed here.

advances to add to the greater discussion about the change of global norms toward RPA lethality.

Strategic Focus

"If there is one attitude more dangerous than to assume that a future war will be just like the last one, it is to imagine that it will be so utterly different that we can afford to ignore all the lessons of the last one."[8] As in any other period of dramatic organizational reduction, J.C. Slessor's timeless advice serves as a valuable guide in 2060, as it did in October 1945 following WWII. With its place reasserted in the world, the military braces for dramatic organizational downsizing. Considering the interwar period context, Slessor promoted a more balanced airpower perspective compared to his British contemporaries when selecting lessons to create an organizational guide for skill retention.[9] By understanding airpower goals and expected costs, states can better decide how to balance airpower composition to deliver strategic and tactical effects. Since world politics is still characterized by the struggle of political entities for power, prestige, and wealth in which states vie to promote their interests, the US must choose wisely as it demobilizes and seeks a peace dividend.[10] This discussion becomes more important now that the US has reemerged from the war of 2057 as the dominant power among free nations. The uncertain nature of the next war represents a formidable challenge to any recommendation.

Recall from Chapters 2 and 3 that Robert Gilpin's work suggests three courses of action that guide a hegemon to address the challenge from a rising power.[11] Following the victory over China, economic realities have helped policymakers that advocate for reducing overseas expenditures to gain political power within the US. The international

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[8] J.C. Slessor, *Air Power and Armies*, (Tuscaloosa, AL: University of Alabama Press, 2009), Introduction, iv.

[9] J.C. Slessor, *Air Power and Armies*, 88, 89, 91-97. Slessor is a great contextualizer. At a time when many in the UK were advocating for an overwhelming embrace to prepare for strategic bombing despite its untested nature, Slessor points to lessons learned from WWI to defend some diversion of effort to those air disciplines that had proven useful earlier, namely reconnaissance, interdiction, and close air support, in addition to strategic bombing.

[10] Robert Gilpin, *War & Change in Politics*, 230.

[11] Robert Gilpin, *War & Change in World Politics*, 192, 208, 216. When faced with the challenge from a rising power, the declining hegemon can disengage from some international obligations, pursue a negotiated reordering, or pursue a series of limited wars against the challenger.

institutions that the US has worked so hard to cultivate are sufficiently mature to propagate a form of the national values.[12] These regimes seem relatively secure in the new international order. As the US reorients its focus toward wealth creation, it should retain airpower lessons that foster quick adaptability to counter emerging threats by emphasizing the ability to promote discovery and innovation. The US seeks a strategy that affirms a commitment to the search for military technology discovery while deferring the large-scale production until needed.[13]

The US' ability to retain critical elements of its innovative workforce reinforces an orderly response to imminent budgetary reductions in 2060. At the strategic level, the U.S. should devise an approach like that of the German effort following WWI to retain critical techniques and skill-sets from which to reconstitute technically superior and well-envisioned air force capabilities to counter an emerging threat. Colonel General Von Seeckt established a forum to capture relevant operational lessons of WWI essential to a well-balanced air force.[14] This technologically superior emergence was accomplished despite the Treaty of Versailles which imposed a number of severe limitations upon German war making abilities, including the exclusion of an air force.[15]

The Germans used their ability to innovate to produce a number of well-reasoned studies and conclusions.[16] The successful re-emergence of the lethal German air service in the mid 1930s validates this approach to creating an adaptive organization in a cost constrained environment. As an added benefit, the airmen working these analysis projects gained familiarity with creating such technical deliberations. Empowered with a

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[12] Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy*, (Princeton, NJ: Princeton University Press, 2005), 9.
[13] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 243-44. Rosen advocates Type II flexibility development which seeks to invest in the maturing process for a variety of R&D efforts. He would promote efforts to achieve Technology Readiness Levels (TRLs) of 5, 6, or 7. He recognizes completing the low-cost portions of technological discovery, while holding off in production until one knows they will likely be needed in war.
[14] James S. Corum, *The Luftwaffe: Creating the Operational Air War, 1918-1940*, (Lawrence, KS.: University Press of Kansas, 1997), 51-52. Von Seeckt held the rank of Colonel General, the highest rank of the German military.
[15] James S. Corum, *The Luftwaffe: Creating the Operational Air War, 1918-1940*, 49.
[16] James S. Corum, *The Luftwaffe: Creating the Operational Air War, 1918-1940*, 61-62. Corum described a four-part discovery process used by the Germans in Von Seeckt's day, which included: a question (representing the hypothesis), study assessment in favor of position, refutation study assessment, and then conclusions reached by the larger peer group. The conclusions were reached after deliberations and provided direction for additional work.)

broader perspective, they recognized the validity of a conclusion to achieve strategic objectives.

Critics may point to the eventual outcome of WWII to write off the German efforts to preserve the most dynamic elements of its military apparatus. However, after reconstituting itself in the 1930s, the Germans arguably emerged with the world's leading land and air forces, despite having to build them from scratch. The fact that the Nazis chose to squander this lethal military force shows that subsequent decision making can undermine previous good moves.

States driven primarily by external motivations reflect a strategy to construct military power in response to some anticipated threat – a threat-based approach. An enemy's action generates a reaction, as captured by a threat assessment. Clodfelter argued that a state should seek to learn the nature of the enemy, the types of war that enemy prefers, and the anticipated nature of the combat environment.[17] Political elements should align to focus national power against the threat. Objectives could range from undermining a state's prestige to annihilating the opposition. A threat-based approach for air power is warranted when a state has limited resources. In the absence of a clearly defined threat, however, building the capacity to perceive and assess emerging threats becomes even more important.

Strategic Focus: Warden's Guide for the RPA Context in 2060

With the Chinese threat thwarted by the asymmetric advantage of the world's most effective weaponized aerial network, a concerted focus on retaining the critical aspects of the Unmanned Network warfare architecture commences. The *Future Picture* for the 2060 case study shows the need to cultivate the innovative elements to the RPA acquisition infrastructure. Simultaneously, the production replenishment rates slow drastically to reduce budgetary costs. The context demonstrates the need to sustain the ability to operate within collaborative RPA networks.

The changing norms to target identification and authentication unleashed the lethal elements to overwhelm the Chinese within the aerial battlespace. The coordinated

[17] Mark Clodfelter, *The Limits of Air Power: The American Bombing of North Vietnam*, (Lincoln, NE: University of Nebraska Press, 2006), 218-19.

US attacks overwhelm the Chinese pilots and RPA operator locations. The Americans seem able to adjust to maximize concentration in the heat of combat. The organizational restructuring in acquisitions contribute most to the overwhelming American success. RPA lethality restrictions become relaxed in the conventional conflict.[18] Automated targeting recognition algorithms prove reasonably effective at minimizing noncombatant casualties from RPAs, despite urban combat in many places.[19] This conventional war serves RPA advancement by revising the formerly prohibitive international norms.

With the *Future Picture* characterized, Warden next advises organizations to consider where they intend to take the organization within the anticipated operating environment.[20] Deep military budget reductions persist in 2060. Warden's key descriptor of market position seems to overshadow most others, in the sense of guiding organizational decisions during personnel reductions.[21] The USAF leadership recognizes that it wants to preserve the innovative portion of the acquisition organizations.[22] In particular, USAF leadership recognizes the RPA networking expertise as a lynchpin to the RPA group autonomy. Also, the RPA architecture office should remain intact. The scalable platform-centric SPOs that contribute artifacts to interact as part of the RPA network are prioritized in order of sustaining capabilities with anticipated future threats. Finally, in orienting the innovative engines of AFRL towards a flexibility-based philosophy as proposed by Rosen, AFRL allowed its focus to disperse.[23] The engineers are encouraged once again to pursue a variety of technology discovery efforts, while the USAF chooses to develop few R&D programs further. This approach optimizes the balance between discovery and cost constraints.

Organizational Aspects: New Norms Embraced after Threat Subsides

Embracing the central tenets of the new overarching RPA architecture office, the acquisitions community has firmly adopted the new organizational arrangement. The proposed associations that hold the realization of RPA group autonomy together clearly

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[18] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011.
[19] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011.
[20] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63-64.
[21] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 65.
[22] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 65.
[23] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, 244.

accepted the roles that were assigned to them.[24] SDRs common to the RPA network are managed by the architecture office. The contributing SPO elements sustain acquisition excellence for unique RPA designs. In order to sustain this dichotomy, leaders within RPA architecture office must resist the temptation to micromanage RPA platform design. Members of the design SPOs have tacit knowledge of how to balance the demands to create RPAs.[25] Cumulative design experience is difficult to displace.[26] One of the architecture office's most important tasks requires continual nurturing of the SPO element capacity to design unique RPA platforms. Additionally, the architecture office management must communicate the need for common SDRs effectively.

Technology Trend Observations

Automated target recognition works against the realization of autonomous RPA cooperative control applications. The primary objections surround lethal applications. The desire to maintain human agency in execution often undermine the ability to achieve such effects. Figure 1 (p. 87) shows that between 2050 and 2057, the effort to ensure human oversight of such activities sustained many still assigned to operate the RPA autonomous networks. The major combat operations with China in 2057 ultimately alter the human-to-RPA ratio. Barring a significant technological breakthrough, society changes because they need to rely on the autonomous technologies to promote victory.

Even in 2060, humans remain very much in control of their stand-off weapons of choice. Humans provide unique attributes to any fight, such as the ability to infer, innovate, analyze, and assess, even in highly automated environment.[27] They possess vivid imagination, creativity, and innovative ideas. They can observe how the enemy acts to a scenario and devise a counteraction that optimizes available resources.

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[24] Michel Callon, "Society in the Making," in *The Social Construction of Technological Systems*, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., (Cambridge, MA: MIT Press, 1989), 93.

[25] Etienne Wenger, *Communities of Practice: Learning, Meaning, and Identity*, (Cambridge, United Kingdom: Cambridge University Press, 1998), 251-52. Wenger's organizational concept of a community of practice describes the resident know-how sustained within the SPO elements. These organizations preserve the histories of learning as living practices future members.

[26] Etienne Wenger, *Communities of Practice: Learning, Meaning, and Identity*, 251-52.

[27] Bob Seidensticker, *Future Hype: The Myths of Technology Change*, (San Francisco: Berrett-Koehler Publishers, 2006), 213-18. Seidensticker presents a number of fallacies pertaining to the extent of technological hype. Perception is subject to distorted expectations about the future, while discounting the discovery breakthroughs of the past.

For an autonomous process, an RPA would rely upon an algorithm to identify the objective using imagery and screen out superfluous items. Numerous factors work to obscure this process, leading to the problems of missing the target or triggering a false alarm. Some elements that confuse the algorithm for a correct identification include imagery magnification, aspect angle, range obscuration, and inability to exclude unknown features that the algorithm does not anticipate.[28] Human misses could result from operator overload, the lack of situational awareness, or even complacency or boredom; the list is large.[29] Future applications will have to assess the maturity of this ATR technology and decide how it will become involved in platforms intended for multi-RPA cooperative control.

Strategic Opportunities

Automatic target recognition represents the most challenging technology to incorporate into the RPA network operations during the previous period. The USAF displays a certain level of restraint while using its RPAs in the aerial battlespace. The service becomes conditioned to this attitude towards operations during numerous IW engagements as far back as 2009-2010.[30] Barring significant technological breakthroughs, society changes to address the conventional threat posed by China in 2057 to use its RPA network in a more lethal way.[31] Although ATR innovations improve, the technology still lacks superior performance capability in numerous aspects. As the definition for evaluating operational limitations for lethal performance change under the new context, strategic opportunities focus on an approach to sustain the most important applications during the following demobilization initiatives.

[28] Meir Pachter, Air Force Institute of Technology, Interview, 12 February 2010.
[29] Meir Pachter, Air Force Institute of Technology, Interview, 12 February 2010.
[30] Joint Center for Operational Analysis, *Transition to Stability Operations (TSO) in Iraq*, Executive Version, 15 December 2010, 11. General Odierno, commanding general of USF-I is referenced as saying that most of the tools must now must be non-lethal. Also see Army Combined Arms Center, *COIN Lessons Learned*, Fort Leavenworth, KS, 28 October 2009, 19, 39. This presentation suggests that the best weapons used in COIN are not lethal ones, and the coalition will lose if it continues to respond conventionally to unconventional attacks.
[31] Corey Schumacher, Air Force Research Laboratory, Interview, 18 February 2011. During the interview, Schumacher talked about a general conventional threat that would force the US to reconsider its approach to RPA lethal applications. The scenario posed in this essay identifies China as a rising challenger that would fit such a description.

The US should embrace a threat-based approach when developing airpower in the future. This is particularly important to US military strategists, since American national strategic culture typically demonstrates a natural indifference to threat-derived strategy.[32] In other words, the US prefers to develop airpower using a capabilities-based approach, even though it should favor a threat-based one instead.[33] The US has demonstrated the ability to overcome airpower mismatches in past conflicts; however, this may not hold true in the future. The US is in an era of declining resources relative to emerging competitors, increasing the importance of a threat-based approach to avoid airpower mismatches.

Conclusion

This chapter considers how the USAF acquisition community will adjust following the conventional showdown with a rising state challenger. After China's defeat, policy makers recognize the need to reorient state resources to foster sustained wealth creation. A concerted effort to demobilize personnel and resources commences. National defense benefits greatly when its military services foster innovation and ensure the ability to regenerate strategic advantage to thwart any emerging threat. Following the conventional war in 2057, military leaders identify the RPA autonomous network as a critical technology worth preserving despite the draw down in forces. This special prioritization should include artifact and organization to sustain and grow the capability for RPA group activity. Finally, this chapter recognizes the change in norms towards the shortcomings of ATR. Norms change when challenged by acute threats. Also, US leaders should emphasize that threat remains an important variable when innovating for acquisitions.

[32] Colin S. Gray, *Explorations in Strategy*, (Westport, CT: Praeger Publishers, 1998), 94-95.
[33] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military*, (Ithaca, NY: Cornell University Press, 1991), 244. Rosen's presentation of capability-based approach to acquisition was previously simplified to emphasize a diverse range of development that could become useful in every possible contingency.

CONCLUSION

Overview

This thesis tackles the question, "What hinders the Air Force from capitalizing on Remotely Piloted Aircraft improvements that increase autonomy?" Depending on which attributes of RPA autonomous operations one refers to, the answer varies dramatically. The analysis considers four case studies encapsulating a generalized trend that considers the maturity of RPA autonomous technology. By using the best information available to plot a trajectory, people working on the issue will begin to find ways to connect their tasks to the strategic game plan.[1] Such an approach improves the probability of success in terms of achieving the objective, in line with the purpose of having a strategy in the first place.[2]

In order to characterize the attributes of the case study, the analysis draws from four dimensions to analyze the context relevant to each case study: strategic focus, organizations, technology drivers, and appreciation for the interfaces between them. While researching aspects about communication barriers between sub organizations within the USAF RPA acquisition community, disparate motivations between the entities became quite clear. The research community often pursues autonomous RPA capabilities as the desired end state, rather than viewing each program as a way to achieve the end. When decision makers seek advice from those motivated as such, they are in danger of losing sight of the strategic drivers.

Why is the Air Force Hindered from Capitalizing on RPA Improvements that Increase Autonomy?

[1] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, (Montgomery, AL: Venturist Publishing, 2002), 8. Warden refers to this process of creating a common framework by a strategic thinking process he calls the Prometheus Process. As specificity is added to the framework, workers can motivate their efforts beyond task completion. They will begin to look for efficiencies to connect their work to those of others for strategic purposes.

[2] John Warden, *Winning in Fast Time*, 7. Warden uses this assertion to motivate the purpose for his book. This essay weaves this theme throughout the entire essay, thereby making a similar case for the development of RPA autonomy.

A confluence of factors may make the realization of RPA autonomy a challenging endeavor for the USAF. One of the biggest threats to the realization of group-centric autonomy developments resides in the success of the American military's way of acquisition. The DoD, most notably the USAF, has cultivated a robust acquisition community for the duration of its history, and the SPO construct has contributed greatly to its success. This organizational method works well for platform-centric production and should facilitate autonomy enhancements for single RPA operations. As a result, the USAF will excel at converting the platform-centric autonomy objectives, but will struggle to realize the group-centric objectives. The organization will struggle with its inability to control SDRs across platforms, jeopardizing interoperability within an RPA network.

A second major contributor to this inability to adapt the organization model resides in American prosperity. One cannot fault prosperity itself. Abundance in resources has accentuated perhaps one of the strongest tendencies of the US research arm. The American national strategic culture typically demonstrates a natural indifference to threat-derived strategy.[3] In other words, the US prefers airpower development using a capabilities-derived approach, even when it should favor a threat-based one instead. The US has demonstrated the ability to overcome airpower mismatches in past conflicts by pouring money at the problems to improvise weapons after the kinetic war has begun. Although a wealthy nation can revert to this if needed, the problem occurs when the resources are not available in the future.[4] The ability to explore alternatives faster than one's enemy does reduce risk during conflict.[5] The US faces an era of declining

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[3] Colin S. Gray, *Explorations in Strategy*, (Westport, CT: Praeger Publishers, 1998), 94-95.

[4] Central Intelligence Agency, *The World Factbook*, http://www.cia.gov/library/publications/the-world-factbook , October 2010. Economic projections in 2010 reveal that the US has a Gross Domestic Product (GDP) of $14.26 Trillion based on official exchange rates, with an estimated -2.6% real growth rate, reflecting the recession of the day. China's equivalent GDP is estimated at $4.909 Trillion, with an estimated growth rate of 9%. Also see Internal Revenue Service, Federal 1040 Instructions 2009 (Published Jan 2010), p 100. Reveals in the Fiscal year 2008, federal income was $2.524 trillion and outlays were $2.983 trillion, leaving a deficit of $459 billion. Of this, Consumption (social security, Medicare, retirement, social programs) totaled 57% of the outlays ($1.70 trillion) and protection (National defense and law enforcement) totaled 26% of the outlays ($0.775 trillion). For simplicity, one could assume that the physical, human, and community development were entirely investment related (9% at $0.268 trillion), although that assumption is unreasonably high.

[5] Grant T. Hammond, *The Mind of War: John Boyd and American Security*, (Washington DC: Smithsonian Books, 2001), 123-24.

resources relative to emerging competitors, increasing the importance of a threat-based approach to avoid airpower mismatches.

Resistance to change represents a final point that this research brought to the surface. AFRL should represent the engine of change and innovation for the benefit of the greater USAF. AFSOC capitalizes from this attribute, almost pushing their operators to the perceived extreme of innovation.[6] The difficulty comes when asked to contemplate the purpose of the effort. Does group-think hinder adequate reflection here, offering an illusion of invulnerability among researchers at AFRL?[7] Some try to convey an understanding about how their efforts contribute to the strategic needs of a warfighter. This attitude could become contagious, thereby increasing the USAF's ability to deliver on the group-centric autonomous developments to realize a heterogeneous RPA network.

Each chapter considers the threat posed by a credible state challenger that could threaten US hegemony.[8] The thesis is purposefully ambiguous as to whether this realization occurs as a well-reasoned recognition of the grand strategic elements, or whether it occurs as an eleventh hour attempt to stave off seemingly imminent defeat. The stakes of inaction increase if an organization like the USAF waits until a rising challenger strengthens to the point that it can dictate change. On the other hand, changing too soon creates problems as well. The work force will more likely resist buy-in towards any cause imposed from above without a clear purpose. Even though powerful personalities help an organization change, individual members decide for themselves about whether to embrace a cause, or seize opportunities to resist the conversion.[9] If the members of the organization are unaccustomed to looking at how their contributions lead to sustaining a larger effort, how will the members of the

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[6] David Jacques, Air Force Institute of Technology, Interview, 16 February 2011. Also note Robert Smith and Caroline King, Air Force Research Laboratory, Interview, 18 February2011.

[7] Irving L. Janis, *Groupthink: Psychological Studies of Policy Decisions and Fiascoes*, 2nd ed., (Boston: Houghton Mifflin Company, 1982), 174.

[8] Robert Gilpin, *War & Change in World Politics*, (Cambridge, UK: Cambridge University Press, 1981), 207.

[9] Stathis N. Kalyvas, *The Logic of Violence in Civil War*, (Cambridge, UK: Cambridge University Press, 2009), 173. Kalyvas' ideas about denouncement opportunities were composed for a civil war context, but extend to the context developed in this paper. Workers have the opportunity to undercut the efforts of other workers, and their supervisors, if they so decide to. What cause is motivating them not to denounce others during a turbulent social reorganization?

organization differentiate between leaderships organizational gyrations? Some organizational changes are clearly needed. Many forced solutions are not.

Strategy to Inform Acquisition Development

From the perspective of 2011, the US should consider strategy as part of its decision-making process. Context associated with the big picture remains important. Warden encourages organizations to promote strategy to motivate its membership about where to go within the anticipated, future operating environment.[10] Using advice from Gilpin, the US should craft strategic interests to guide its decision making.[11] In order to help the nation's policy makers achieve objectives that are consistent with the nation's interests, the USAF should align its endeavors to achieve military objectives that support national priorities. The US has an opportunity to influence through the international order that it has worked so hard to build to project the national values.[12] How does the US sustain its values?

An understanding of strategic purpose becomes particularly important in an era of declining resources available to promote national interests. The acquisition of technologies that contribute to enhanced RPA autonomy will not remain immune from economic pressure. The ability to craft well-defended positions improves when they are linked to some greater purpose. More importantly, understanding strategy will help the acquisitions community realize what it needs to prioritize in the first place. It is the military leadership's job to educate the policymakers about all facets of military power.[13] This leadership should anticipate the near and far term policy objectives and advance strategic proposals to develop airpower that can address anticipated threats. Deliberate communication enables clarity that helps policymakers craft national objectives commensurate with the force structure available. Only then is airpower well positioned to help the state achieve its national objectives. Understanding the national intent best

[10] John A. Warden III and Leland A. Russell, *Winning in Fast Time*, 63-64.
[11] Robert Gilpin. *War & Change in World Politics*, 18, 29.
[12] Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy*, (Princeton, NJ: Princeton University Press, 2005), 259.
[13] Carl Von Clausewitz, *On War*, ed. and trans. Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1976), 608.

positions airpower leaders to reassess airpower effectiveness and recommend modifications.

The Value of this Work Resides in the Nested Frameworks for Evaluation

This thesis captures an assessment of the development of RPA autonomous technologies within the context of the international framework and strategic interests. In each of the case studies, China represents the rising challenger to US hegemony international order. The US should develop RPA technologies as a means to effectively address such a threat. Chapter 2 connects RPA autonomy against IW threats. The ongoing Afghanistan conflict demonstrates the need to project power to hinder Chinese inroads into central Asia. Chapter 3 highlights the need to become focused on a conventional threat. ATR emerges as the latent technology driver that is prohibiting the realization of RPA group-centric power projection. Chapter 4 addresses the need to prioritize strategic elements during a period of retrenchment.

But, how can a strategist really know that his or her assertions are valid at some time in the future? As new developments influence the anticipated context, the assumptions and conclusions require modification. Even a good strategist does not have a glimpse of God's perspective on the matter. The primary value of the work herein emphasizes the methodology to assess this complicated, multi-dimensional problem. As context changes, one can adjust assumptions and reapply the nested frameworks in order to reassess the problem.

Hence, the value of the work resides in the adaptation of Warden's approach to frame the context of the problem. Emphasizing that the interests and relative powers of groups change with time, Robert Gilpin's framework offers valuable insights to a hegemon for potential policy revision for the desired timeframe. Warden's framework then characterizes a strategy that pertains to the organization of interest to align the goals with that of the larger interests – the strategic national objectives.

From here, Theme 1 represents an RPA autonomy-centric characterization that emulates Warden's approach to focus the organization. The merits of this articulation are then broken down into the practical implications pertinent to the relevant organizations, emerging technologies, and strategic challenges. Theme 2 diversifies the acquisition

design considerations. It serves to counter reductionist logic important to RPA technological developments, to include those that enhance a single view of what autonomy eventually looks like. Together, these considerations create the scaffolding to guide the communication that fosters RPA autonomous technology development. Constraining this dialogue to a discussion about a suite of capability options is too narrow. The framework developed in this thesis should help prioritize the focus of communication about autonomy development.

Conclusion

While conducting research pertaining to AFRL's efforts to develop frameworks that are intended to bridge communication about autonomous developments for RPAs, the research process uncovered a dilemma. With some effort, the laboratory could construct some sort of rationale to develop the anticipated interim capabilities en route to realizing autonomy. The thesis assesses what hinders USAF efforts to capitalize on RPA improvements that increase autonomy, particularly for group-centric applications. By developing four case studies to help craft contexts in which one can articulate the nature of the challenges that lie ahead, a strategist can evaluate whether the benefits are worth the costs. In general, the acquisition community does not understand the rationale behind the anticipated acquisition strategy. In fact, the strategic rationale is often missing to start with, and the context clearly changes with time and evolving circumstance.

Ideally, the acquisition community benefits if it knows about the strategic focus of the effort. This insight permits the necessary reorganization and prioritization of technology drivers in order to achieve the contextually clarified objective. No doubt, the acquisition community will endure some unfamiliar hardships and challenges to deliver some of the autonomous developments for RPAs. By thinking about these considerations ahead of time, the organizations become more resilient to strategic challenges that could disassociate the project if left unchecked. The nested frameworks provide a basis for future assessment as contextual components change.

APPENDIX: FIGURES AND TABLE

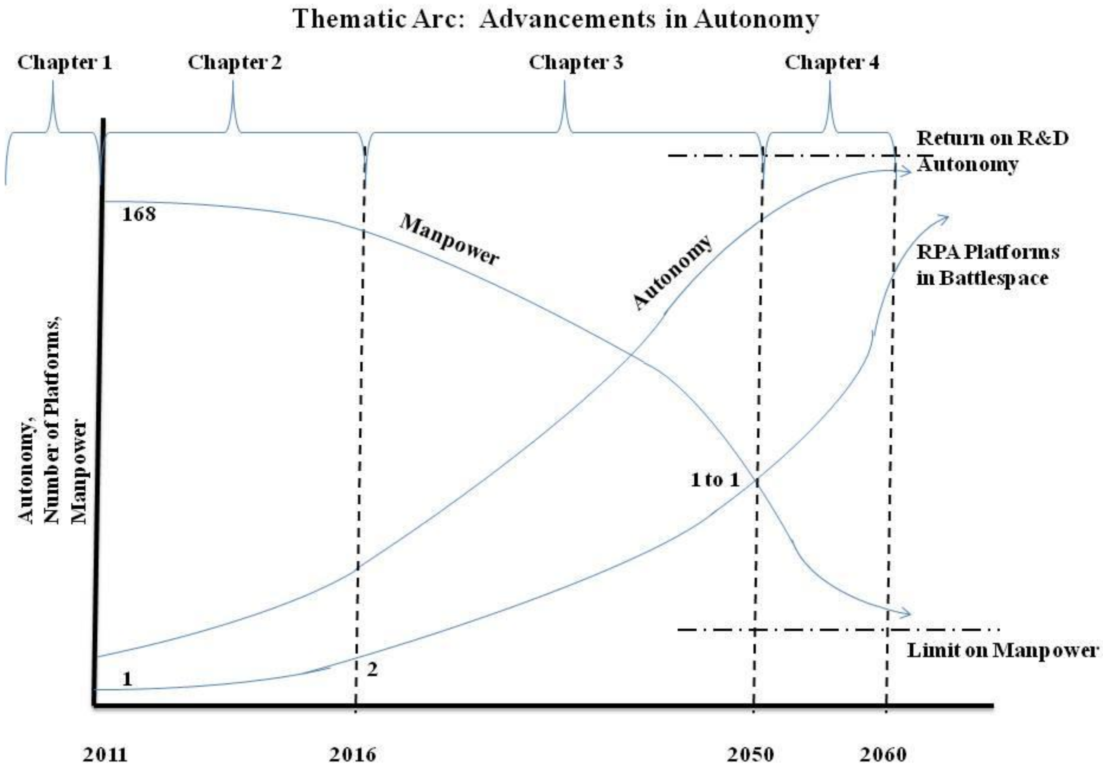

Figure 1. Theme 1 – Advancements in RPA Autonomy.
Source: Author's Original Work

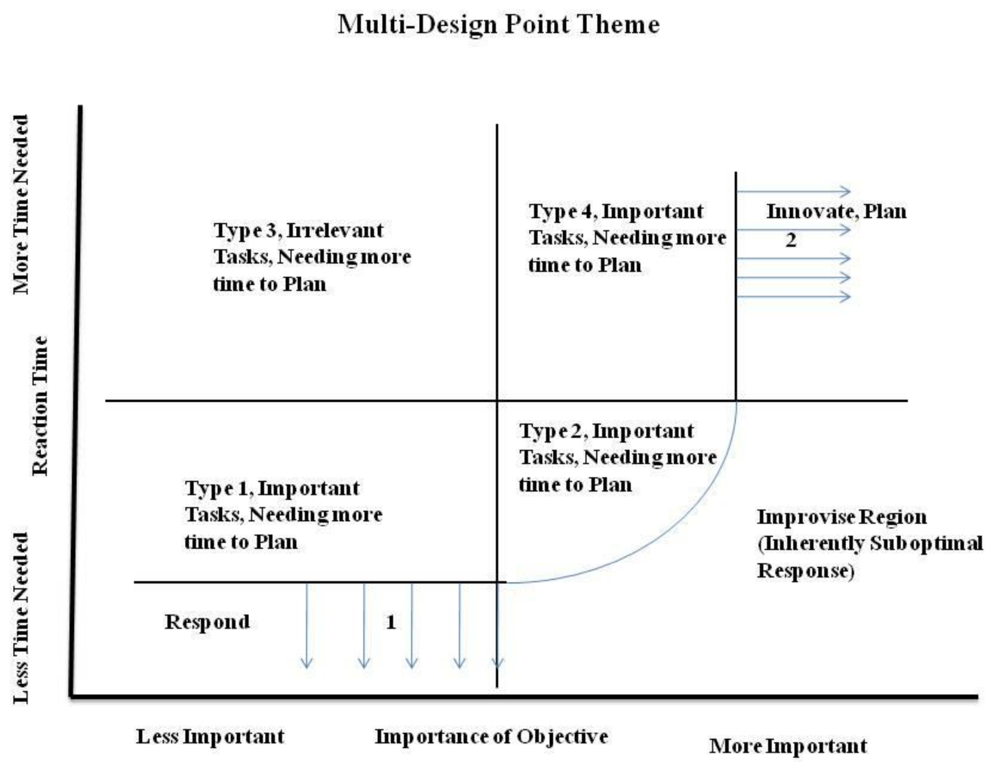

Figure 2. Theme 2 – Multi-Design Points for RPA Acquisitions.
Source: Author's Original Work

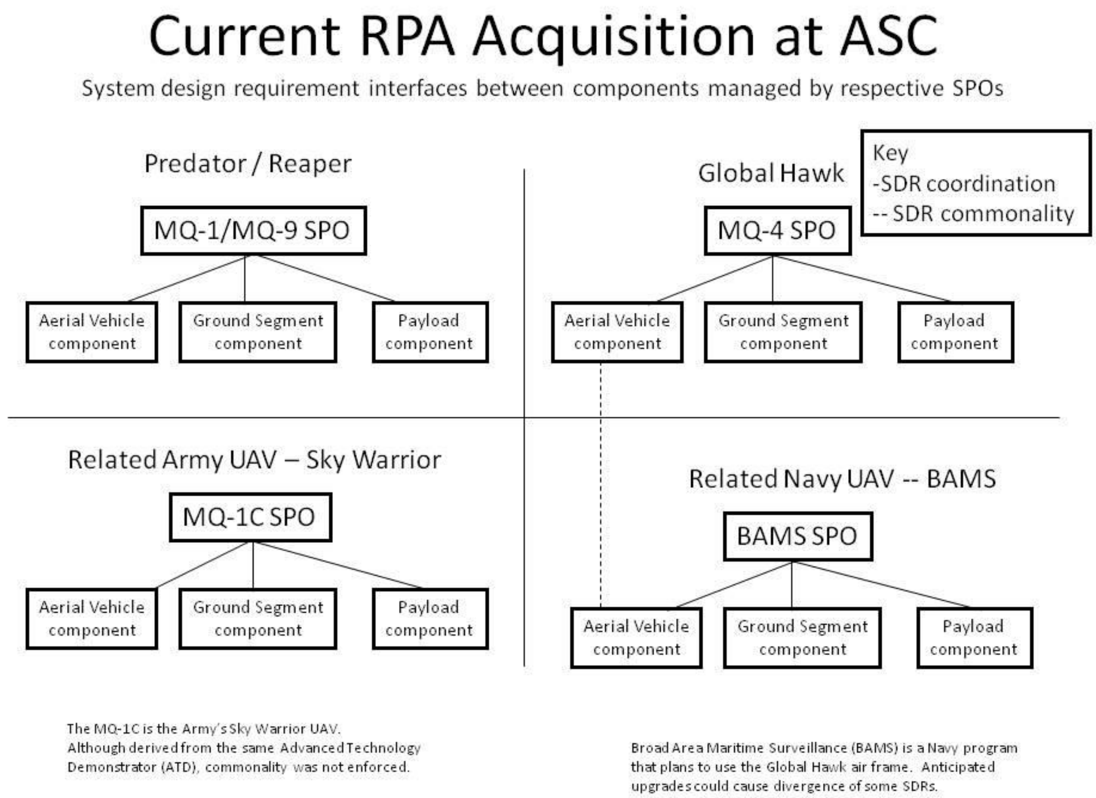

Figure 3. Current RPA Acquisition at ASC.
Each System Program Office customizes its system design requirements to create a RPA that satisfies each program office. It is not conducive to automate a cooperative-control RPA fleet for joint missions. Source: Author's Original Work

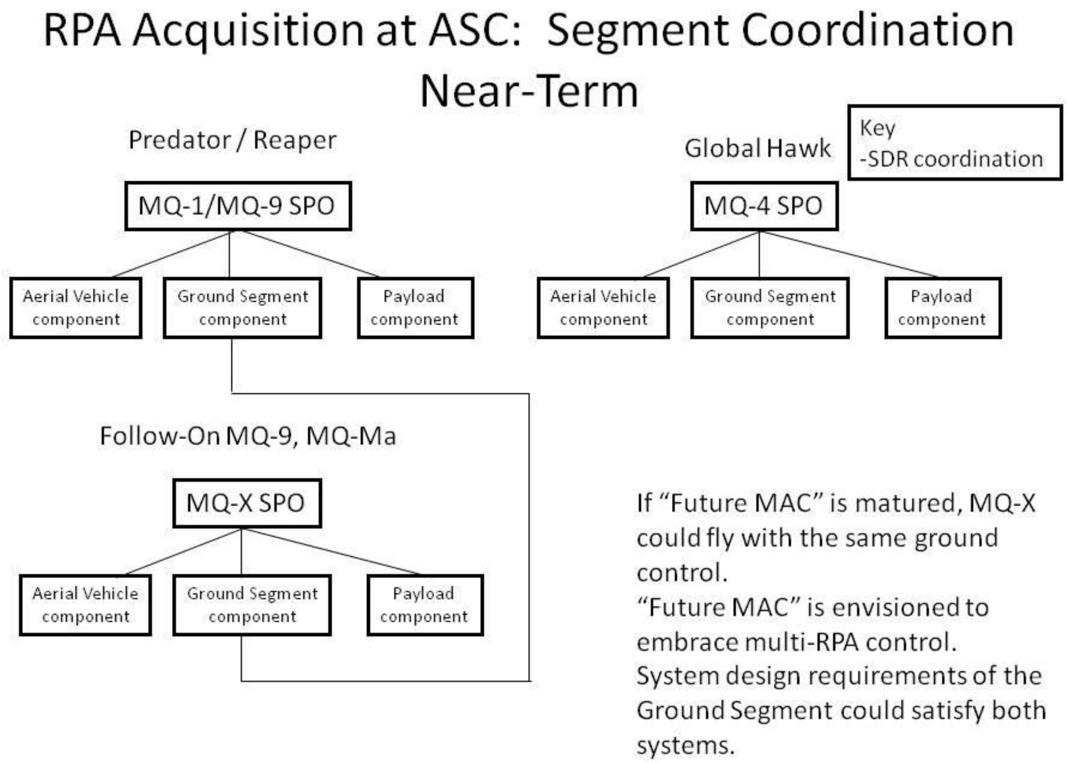

Figure 4. Potential Multiple Aircraft Control Ground Control Segment.
The idea of a future ground controller that controls multiple RPAs simultaneously could coordinate system design requirements between the MQ-1/MQ-9 and the next generation medium-sized RPA, currently designated MQ-X. Source: Author's Original Work

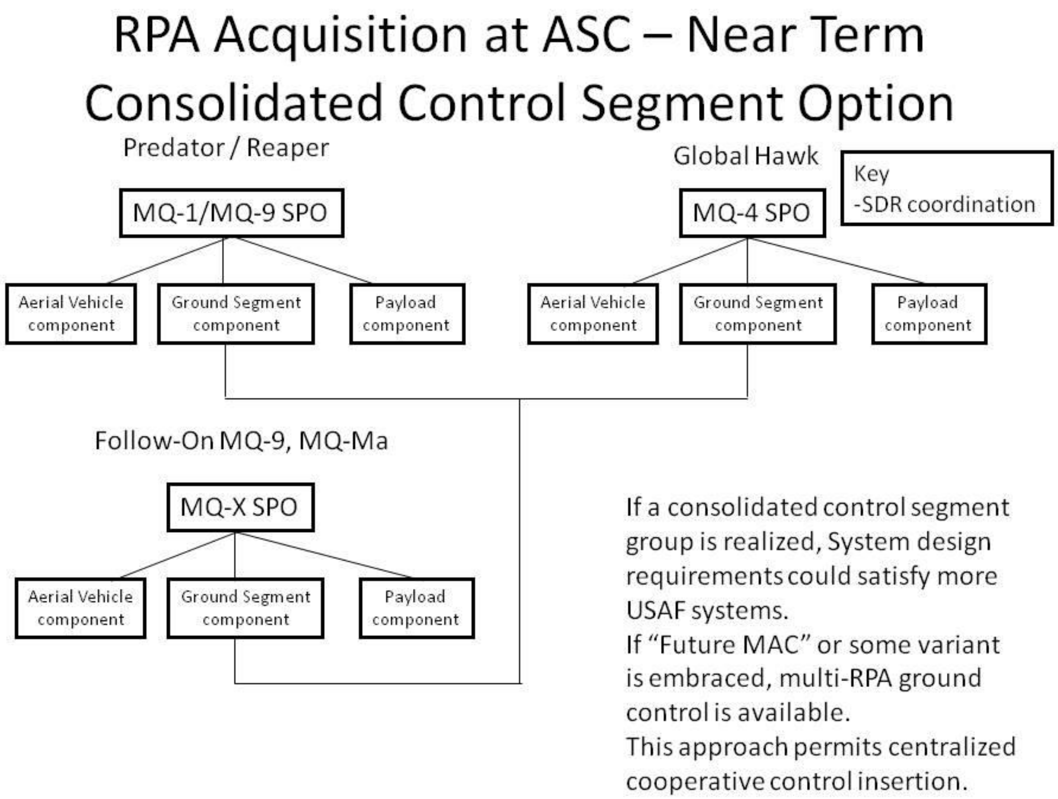

Figure 5. Potential Consolidated Control Segment.
The idea of a consolidated control segment option could work to realize common system design requirements that satisfy all RPA types that are included. This idea merges the future ground controller concept that controls multiple RPAs simultaneously. These two concepts would impose radical changes to the Global Hawk's current approach to commanding its vehicles. Source: Author's Original Work

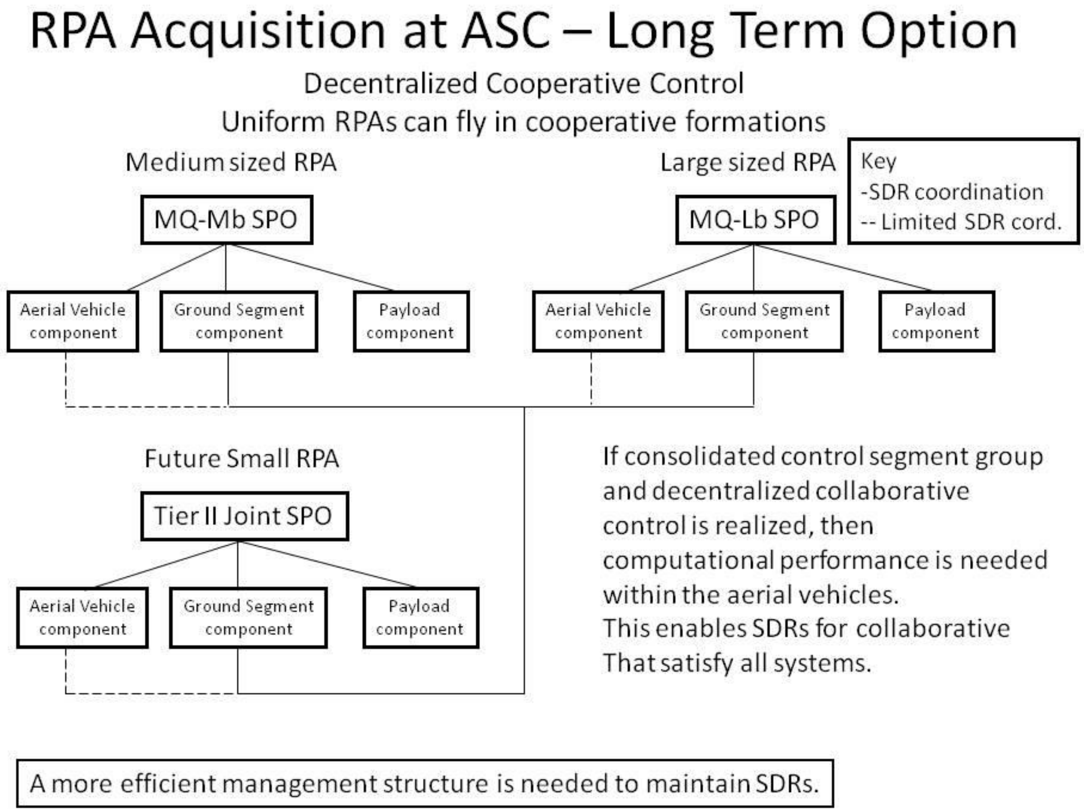

Figure 6. Potential RPA Acquisition Organizational Structure.
In an effort to add robustness to the automated cooperative control algorithms, decentralized cooperative control forces additional design variable trade-offs. Sufficient computational capabilities are needed on-board each aerial vehicle to run these algorithms. Decentralized cooperative control is a component towards realizing cooperative formations. Source: Author's Original Work

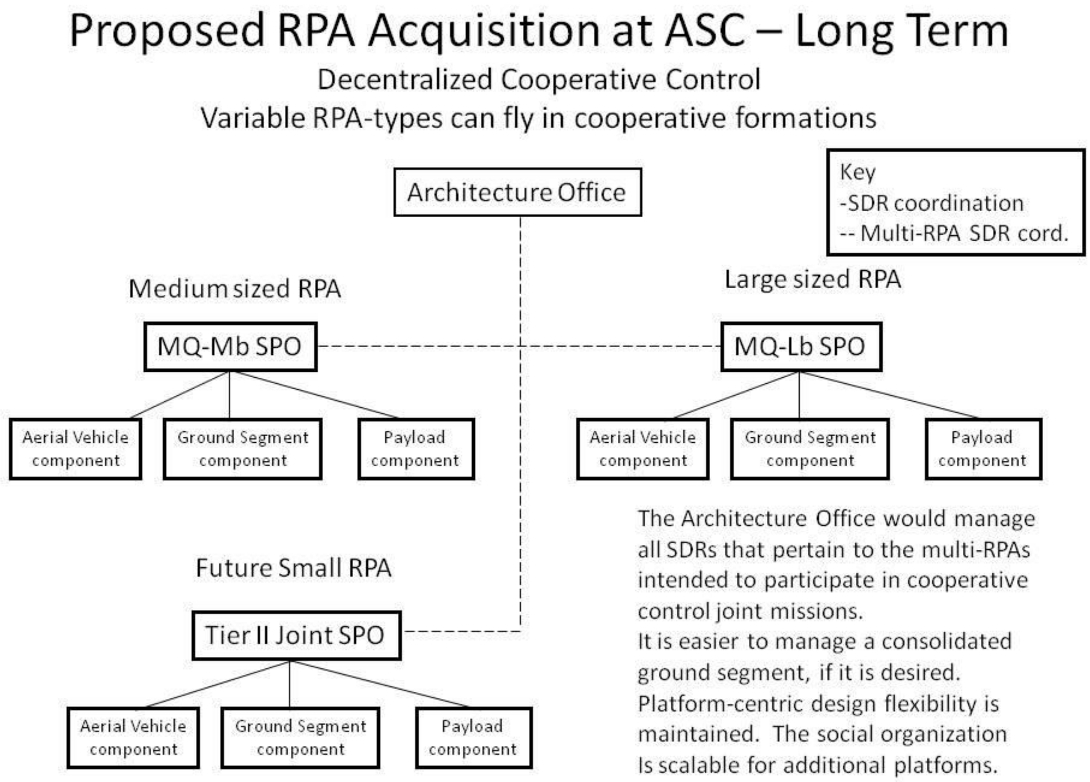

Figure 7. Recommended RPA Acquisition Social Organizational Structure.
The proposed acquisition features an architecture office that controls all SDRs that are needed to manage the multiple RPA intended to interact in a cooperative manner. The system program elements retain control over all remaining SDRs that are unique to the platform acquisition. Source: Author's Original Work

	(Trillions) US GDP	Project Growth Rate	(Trillions) China GDP	Project Growth Rate
2009	$14.26	-3%	$4.91	9%
2010	$13.89	0%	$5.35	4%
2011	$13.89	2%	$5.56	4%
2012	$14.17	2%	$5.79	5%
2013	$14.45	3%	$6.08	6%
2014	$14.88	3%	$6.44	8%
2015	$15.33	3%	$6.96	9%
2016	$15.79	3%	$7.58	9%
2017	$16.26	3%	$8.27	9%
2018	$16.75	3%	$9.01	8%
2019	$17.25	3%	$9.73	8%
2020	$17.77	3%	$10.51	7%
2021	$18.31	3%	$11.24	7%
2022	$18.85	3%	$12.03	6%
2023	$19.42	3%	$12.75	5%
2024	$20.00	3%	$13.39	5%
2025	$20.60	3%	$14.06	5%
	↓		↓	
2030	$23.88	3%	$17.94	5%
2035	$27.69	3%	$22.90	5%
2040	$32.10	3%	$29.23	5%
2045	$37.21	3%	$37.31	5%
2050	$43.14	3%	$47.61	5%

Table 1. Projected GDPs for the US and China.
The statistics incorporate the impact of economic structural change projected in Gilpin's book, in which the aging hegemon retrenches to reduce costs, while the rising power's growth slows, based on an increase in their projected responsibility within the existing international order. This table assumes statistics derived from the CIA World Factbook for the early growth. Source of Projections: Author's Original Work.

ACRONYMS

ACC – Air Combat Command
AFIT – Air Force Institute of Technology, Wright Patterson Air Force Base
AFOSR – Air Force Office of Scientific Research
AFRL – Air Force Research Laboratory
AFRL/RB – Air Vehicles Directorate
AFRL/RH – Human Effectiveness Directorate
AFSOC – Air Force Special Operations Command
ALFUS – Autonomy Levels for Unmanned Systems. A metrics-based framework of RPA autonomous technologies.
AoA – Analysis of Alternatives
AOR – Area of Responsibility
ASC – Aeronautical Systems Center
ATD – Advanced Technology Demonstrator
ATR – Automated Target Recognition
BAMS – Broad Area Maritime Surveillance program (US Navy)
BQM-34 – Vietnam War era RPV
BW – Bandwidth
C3I – Command, Control, Communications, and Information
CAOC – Coalition Air Operations Center
CAS – Close Air Support
CDD – Capability Development Document
CIA – Central Intelligence Agency
CM – Configuration Management
COIN – Counter Insurgency
CONOPs – Concept of Operations
COUNTER – Cooperative Operations in Urban Terrain (an AFRL multi-RPA program)
DARPA – Defense Advanced Research Projects Agency
DoD – Department of Defense
DODI – Department of Defense Instruction
FAA – Federal Aviation Administration
FSA – Functional Solutions Analysis
GAO – General Accounting Office
GDP – Gross Domestic Product
GPS – Global Positioning System
GVN – Government of Vietnam (South)
HLA – High Level Architecture
HSI – Human Systems Integration

IC – Intelligent Controller (acronym specific to journal article written by Jodi Miller, et al.)
ICAO – International Civil Aviation Organization
ICBM – Inter-Continental Ballistic Missile
ICD – Initial Capabilities Document
IDE – Integrated Development Environment
IPP – Integrated Planning Programming
ISR – Intelligence, Surveillance, and Reconnaissance
IW – Irregular Warfare
JCTD – Joint Concept Technology Demonstration
JPATS – Joint Primary Aircraft Training Systems (an Air Training Command program in the 1990s to replace T-37 aircraft)
KPP – Key Performance Parameter
MAC – Multiple Aircraft Control (for MQ-1 Predator and/or MQ-9 Reaper RPAs)
MQ-1, MQ-9, MQ-X – RPA designations (Predator, Reaper, Future Hunter Killer)
NRE – Non-recurring Engineering
POM – Program Objective Memorandum
R&D – Research and Development
RAVEN – a small RPA
RFI – Request For Information
RFP – Request For Proposal
ROA – Remotely Operated Aircraft
RPA – Remotely Piloted Aircraft
RPV – Remotely Piloted Vehicle
SAASS – School of Advanced Air and Space Studies, Maxwell Air Force Base
SDR – System Design Requirement
SE – Systems Engineering
SEAD – Suppression of Enemy Air Defenses
SecAF – Secretary of the Air Force
SecDEF – Secretary of Defense
SEP – Systems Engineering Plan
SME – Subject Matter Expert
SPO – System Program Office
STANG 4586 – A standardization agreement used by NATO that sets out specifications for common RPA ground stations.
TRL – Technology Readiness Level
TSO – Transition to Stability Operations
UAS – Unmanned Aircraft Systems
UAV – Unmanned Air Vehicle (joint term)
UCAV – Unmanned Combat Aerial Vehicle

USAAF – US Army Air Forces
USAF – US Air Force
USD(AT&L) – Under Secretary of Defense – Acquisition, Technology, & Logistics
USMC – US Marine Corps
VFR – Visual Flight Rules
VM – Virtual Model

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